PSYCHOLOGICAL OPTICS

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PSYCHOLOGICAL OPTICS

by

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PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshow, Ph.D. at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PERCEPTION: XLVII

March - 1956

Vol. 16 No. 1

Thus far we have attempted to show that perception, that is, the operation by which we "size-up" and come to understand and act upon the things and changes in our world of experience, is much more complex than can be described in terms of stimulus input, certainly important, or effector output, also most important, or in terms of the many types of shrewd guesses as to what "goes on" in the black box - the brain.

Our contention has been that the perceiving person, almost forgotten by some of the savants discussing the problem, must be reckoned with in any reasonably acceptable treatment of the problem, and that the first and foremost task must be to detail carefully exactly what goes on when one is engaged in any kind of perceiving. That is to say we must examine the process of perceiving.

As Hayek, Klüver and others have pointed out, in the youth of scientific inquiry the objective is the study of things and then attributes. In them was sought the answer to all the questions one might raise about the operations of things.

As science and scientific method matures it is forced to relinquish this position. It discovers that it must concern itself, not with things and attributive properties of things, but with processes and relations. And if I may be so bold as to presume, it must reach a stage, if it seriously works long enough with the problem to reach another stage which I may designate as the relation of relations, in which the first order correlations are studied to see how they can be fitted into the changing pattern of the unified, personal experience of the perceiver. What I am trying to say is merely that relations among processes are meaningless unless we can somehow articulate them with the common phenomenal experiences of you and me. This is empathy. Suppose we cite a concrete example, studied by several of us, more intensely by Chester Pheiffer, in my laboratory. The problem was a "simple" one. How many steps of discriminable difference in size can a person see if a spot or disk or light is increased from one of 5 mm. diameter to one of 300 mm. diameter?

Now at once it must be recognized that in such an investigation, in visual psychophysics, the methods one employs may be vital in determining the degree of trustworthiness of the results.

Suppose we show you two annular spots of light of equal brightness but unequal size. You are to judge whether the one to the right is larger (yes or no) than the one on the left, it being the "standard" and the one on the right being the "variable". You may do one of two things. You may compare R with L, or you may compare L to R. Of course you do not know which is standard because we randomly vary its position, R and L.

But one spot is an object, judged (i.e. perceived) in terms of another. Logically it should make no difference, if the judgement is a response to a relation, whether the pattern of the judgments is L → R or R → L. But it most certainly does! And my mentioning of this fact and citing the high class work of Dr. Chester Pheiffer (and our co-workers) on the problem is done only to show that how the perceiver operates is an important and often neglected determinant of the end result. The processes or operations used by the perceiver are thus just as important for any serious attempt to deal with the problem as any precise fussing with mechanical controls, or refined or elaborate statistical or mathematical handling of the data, which in the end are no better than the conditions controlled by the investigator to yield the primary data. This fact, unfortunately, is often forgotten, as for example, in the controversy in the psychological literature on perception between Professors Postman and Gibson over the relative "explanatory" merits of association or enrichment as the answer to what happens in the process of perceiving more or better in one instance rather than another.

So, in having a look at the processes in perceiving, let us merely ask: What can we get from the experiments which have been aimed at the description of what the perceiver actually does - before, during and after - the act of perceiving? That is the objective in this and some subsequent papers.

I hope that in this series I may be able to show you the weakness of the quotation which follows. It is from a recent book on perception by Professor Allport, and illustrates a point that I have repeatedly emphasized that before one talks about so complex a problem, one should have had enough experimental experience to have earned the right to an opinion. On the question of syncretism, about which we will have more to say, Allport say "if there exists such a thing as a whole, distinct enough from its parts to have laws of its own and to be able to subject the parts to them, then this inference must rest in a metaphysical assumption rather than observed facts. It is ---- not available for empirical invistigation."

I quote this only for one reason. I respect the high competency and scholarship of Allport, but one has the right to question such a generalization as the above. Let us let the facts decide the case. No one can dispute that the very first thing that can possibly happen, when the eyes are stimulated by a visual pattern, is the recognition that there is "something out there." A flash of light at one-millionth of a second is enough to upset the equilibrium. If the flash is eccentric to the visual field orientation, there will be movements of "centering", i.e., establishing a new equilibrium.

In previous papers I have shown that the organism is always doing something, going somewhere, so that the appearance of any energy impact detected by any receptor must set up forces in the field which change the direction or rate or kind of activity. That is to say stress patterns form because rarely if ever is the distribution of forces homogenous and regular. So the very first process in perceiving is this very primitive orientation, centering, posturing, addressing the source of the energy impact, because it is there (in the center) of the visual field that acuity is sharpest, forms are seen best, and there is the very best position in which the surrounding peripheral ground can, through spatial summation or reinforcement, form contours which are absolutely necessary for the subsequent stages in the perception process.

This very early primitive experience on the skin is described as protopathic sensitivity and has its paradigm in the very early stage in the process of perceiving which is a vague awareness of something out there, but what remains to be developed in later stages of the process. What we must designate as the organic field is contributed to by streams of incoming impulses from all the sense organs. So that the primitive early stage of "vague awareness" is the beginning of a process of weighting, combining, suppressing, grouping of the sub-regions of the field, some of which become salient, stand out as figure objects; some recede and operate as the more primitive surrounds or grounds upon and from which figure processes emerge.

This process varies from very weak and poorly organized to very strongly structured, stable and meaning comes because the perceiver reaches the stage where he is aware of the class or type of object out there. He can name it. He knows what it can or will do, how it will affect the stream of his behavior; in other words, the process of perceiving has reached the stage called the stage of the generic object.

It should be noted that there are no "mysterious or metaphysical" terms in the real description of field dynamics in perception - what goes on is merely that you cannot possibly prevent eyes, brains, and effectors such as we have from forming a structure or organization of forces in a field following such real determinants as the laws of precision, good continuation, intensity, closure, common fate, direction, habit and training, set, purpose, etc.

In some people field organization is never anything but weak, disjoined, poorly articulated, hence error prone, partly form blind, poor at retention and recall because the valence or impressability of the inputs from the first could not be dealt with properly because the process of perceiving from the beginning to end, is an active process of organizing and re-organizing the field. It is clear that visual field organization, as an integral portion of the total organic field, may be transformed or distorted, or conversely enhanced and stabilized by activities and distributions of processes in other regions of the organic field. This is why a complete and thorough visual assay must include much more than the purely visual.

Note please that specification, naming and classifying does not come until after the generic object stage. That is to say every experimental study of the processes in perceiving are agreed on one thing: at first we begin with wholes, totalities, generalizations. We get specific object perception only when the active process done by the perceiver has been carried to some point of individuation and differentiation.

And so here perception as process acts just like the analysis of the process of acquiring skilled movements. At first there are vague, undifferentiated mass acts. These are generalized and by differentiation and de-differentiation through practice and training finally reach the stage of individuation. Thus we find consistency, law and order in these two sets of closely similar processes.

Next month we shall attempt to describe the next stages in the perceptual process.

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PERCEPTION XLVIII

May - 1956

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In the preceding paper of this series, a descriptive account of the stages through which the processes of perceiving passes, was started. It is helpful to understand or apprehend (i.e. literally, get hold of and handle) that in perceiving an object, thing, person, melody or printed word, the process in time may be 'instantaneous'. That is, it may be an exposure of only two millionths of a second, which is long enough to trigger off the subsequent receptor-distributor-effector-feedback events. Or, it may run an extensive course in time, wherein from the first impression of the receptors (the eyes) the search or effort to attain meaning can be examined throughout its course.

There are a number of laboratory techniques, developed to make possible the measurements, and descriptive control of the analysis of the stages through which the process passes. Later more about these.

This procedure of the controlled slowing down, without distorting a process, has been known and utilized for quite some time. A good illustration happened a few years ago only a few blocks from where these lines are written.

A world famous golfer was here for the National Open Championship Matches. In his books and private lessons every one of his pupils was admonished "Now, in using your driver, be careful never let your hands get ahead of the club head." Then he would swing slowly to emphasize and show the relative positions of his hands and club head.

A friend, a mechanical engineer and inventor, did not believe that, within limits, the relative positions of hands/club head was a determinant of the direction and distance of the stroke. So he built a camera which could take a thousand frames a second. He arranged with the famous golfer and recorded in slow motion many shots.

No. one was more surprised on viewing the films than the golfer himself, because the slow motion enabled anyone to see plainly that he never hit a ball off the tee except with his hands well in the lead of the club head! One may also point out that the introspective, rational and logical report or opinion about a functional process or operation may be wrong as often as right, even unwittingly so. I am sure the expert golfer sincerely believed that he hit the ball better when the hands trailed back of the club-head.

I should like to emphasize again the fact that no pattern of impression ever reaches the perceiving person in a completely neutral state, with respect to the nature of the impression object.

The visual field, for anyone old enough to be able to walk and talk, is anisotropic. That is, upper and lower and right and left quadrants have topological but not geometric equivalence.

And, similarly, even though one tries to imagine a hypothetical case of a pair of identical twins reared in the 'same' environs and sharing always 'the same' experiences, the probability that the processing of the input 'information' would result in identical meaning and consummatory acts for each of the two persons is not likely to be greater than chance or greater that the similarity between any two siblings reared in the 'same' environs.

The extreme empiricist holds the view that we all started out in life as tabula rasa.

blank pages, and that all the psychological constructions of perception and action were built into the system by learning and experience.

For them, functions develop from a zero origin, while for the opposing nativists functions appear and develop when the appropriate optological stage is reached.

I find great difficulties in wholly accepting either of the above theories, yet much in each which no one can deny.

One difficult thing is to find some authority who can render a rigorous definition of "learning and experience". The attempt to answer "What is learned?" usually ends in some kind of speculation, based on partial and incomplete knowledge as to what happens in the brain. Professor Gerard, a very famous neurophysiologist, has frankly stated that what the brain does in remembering is at present unknown. And Professor Adrian, also eminent in his field, sums up what neurophysiology has contributed to our more complete understanding of perception in a single word; nothing.

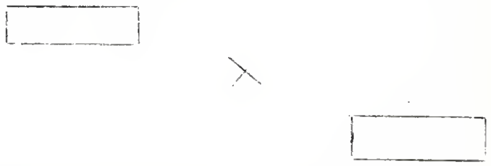
Surely, "it is easier to know what 'twere good to do, than to be one of twenty to follow mine own instruction." Experience may or may not be the best teacher. It seems to depend on a whole complex set of events which both precede and follow experience.

The late Professor Koffka aptly criticized the experience theory of perception and learning by pointing out that it "both explains too little and too much." But we must recognize that the very concept which we designate as intelligence involves the primary ability to profit by experience. The only question seems to be how and how well we are able to do it.

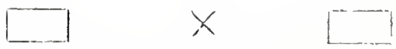
No one can dispute the fact that hysteresis effects are produced in proroplasmic systems. Look, for example, at the well known facts of immunization and sensitization.

Changes or alterations of the mechanism may be induced which alter or distort forms, etc., which involve the operations subsequently of the same region. If one looks for 30 or 40 seconds at the central point from which 36 radial lines like the spokes of a wagon wheel originate, and then removes this from the visual field and passes a pair of parallel lines symmetrically through the point of origin in any meridian, the parallels will not be seen as parallel but bowed out in the region of the center. If one maintains the line of regard on this central point and at the end of each five seconds exhibits the parallels for an exposure of 1/10 second, one can measure the duration of the distorting effect. It may last from 30 to 120 seconds depending on the individual observer. The distorting effect of previous activity or experience is thus transient. Kohler and Wallach examined many cases of figural after effects of different forms, inspection times, etc., and found that some of the figural after effects were much more stable and lasting than others, some lasting for hours and showing that in all liklihood with repeated satiation (establishing a state of electrotonus in the cells of the brain) effects might be produced which may remain indefinitely. Kohler showed that the same effects could be produced on the skin. And Dr. R. J. Christman in his dissertation in my laboratory showed that the same kind of effects could be produced with tones of different pitch frequencies.

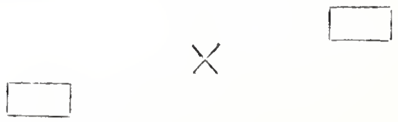
When two rectangles (Inspection objects) were seen for 40 to 180 seconds, fixating at point X



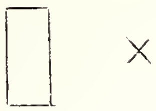
and later was shown two smaller rectangles (Test Objects)



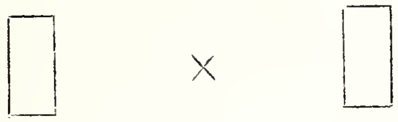
the small rectangles were seen displaced in space as



the left being displaced down and the right upward with respect to the positions of the two inspection rectangles. When a single rectangle was shown as an I object



with the region to the right of the fixation *X* blank, and later a pair of similar rectangles was shown



the figure on the left coinciding with the I object above was "pale or grey in comparison with its black partner, it will seem to be *farther back in space*, and it may look a *trifle smaller*."

Note that the distortion of the planar figure was, among other things, moved back in space along the *Z* axis.

In other experiments Kohler used inspection figures in three dimensions and found that here the effects were more striking, easier to produce and were therefore most likely manifestations of the hypothesis that three dimensional visual experiences are more fundamental and primary than are the two dimensional or planar effects.

From these observations Kohler very cleverly worked out his hypothesis that these effects had to be produced by the action of direct currents in the brain. You can read the full account in Proceedings of the American Philosophical Society, 1944, Vol. 88, 269-357 and also in his more recent exposition the Hixson Symposium volumes on Cerebral Mechanisms.

There can be no doubt that traces are left by our visual experiences. These may become processed and programmed to serve as constraints or as determinants of the vector outputs which follow upon stimulation and perception. The organization or structuring of these impression effects has been called syncretism. From our own investigations of the processes of grouping in visual form perception by tachistoscopic methods we are convinced that skill in syncretic grouping can be acquired to a high degree and that when so done can and does radically transform and extend the accuracy, range and speed of perceiving.

In a book *Studies in Neurology* (1920) Sir Henry Head wrote: "The Sensory Cortex is a storehouse of past impressions. They may rise into consciousness as images, but more often, *as in the case of spatial impressions*, remain outside central consciousness. Here *they may form organized models of ourselves*, which may be called Schemata. Such schemata modify the impressions produced by incoming sensory impulses in such a way that the final sensations of position or locality rise into consciousness changed with a relation to something that has gone before." A dozen years later (1932) Professor Bartlett objected to Head's statement on three grounds. First, that the cortex is a storehouse of past impressions, second to "rising into consciousness" and finally to Head's concept of *schema* which "suggests some persistent *but fragmentary* form of arrangement...and it does not indicate what is very essential to the whole notion, that the organized mass results of past changes of position and posture *are actively doing something* all the time."

Bartlett elects to retain the term schema, but to give it a different meaning. Schema, he says, "refers to an active organization of past *reactions*, or of past experiences, which must always be supposed to be operating in any well adapted organic response...whenever there is any order or regularity of behavior, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members, coming one after another, but as a unitary mass...each set of incoming impulses...have to be regarded as constituents of living, momentary settings, *belonging to the organism*....and not as a number of individual events somehow strung together and stored within the organism."

So, very early, indeed, in the process of perceiving, we see that what the sensory input brings to the organism, will, if it can, be assimilated into the stream of oriented outgoing behavior process already actively in progress toward some end or goal, of which we may or may not be aware. Perception thus is a transitive process, or it is nothing.

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PERCEPTION: XLIX

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The term *schema*, used by Head and by Bartlett in two different ways, represents a concept of the first order of importance for perception. Both of the above statements are, as I see it, partly correct; neither is wholly so. Let us examine Bartlett's formulation, stated in the next to the last paragraph of Vol. 16, No. 2.

Schema (plural schemata) refers to "an *active organization of past reactions*, or of past experiences." Clearly the perceiver as a person, an active, cognitive, substantive person, processes or organizes the information of instigatory character supplied by the receptors, and also that of the backstroke or feedback mechanisms reporting the extent, significance, empathically, of the immediate prior acts and experiences as they relate to the whole behavior life history of the perceiver.

One strong argument for this view is the emphasis on the fact that the process of perceiving not only refers to the cognitive or understanding aspect, but it also points up the fact of the conative or action aspect of the process. The driver of a motor vehicle may have a complete understanding of every traffic control law and yet he may in actual driving be a highway menace.

As I see it, no perceptual process can possibly begin in sense organ activity and end in the brain. Even if it were inhibited in the cortex, this is a form of implicit action. Only when some executant movement of speech, oral or internal, manipulation or locomotion *precedes* and *follows* the grasp or *understanding of the signal* does meaning accrue. The late Professor Tichener said quite clearly and cogently that "The common demoninator of meaning is kinaesthesis".

This is attested by the well known fact that the mimesis or "acting it out" in the old silent movie was perhaps the most effective means of telling a story ever devised. Every viewer of any race, sex, age or linguistic type could "according to his lights" understand the story, for actions do speak not only louder but clearer than words.

All of which means essentially that what anyone gets from a lecture, sermon or a printed document is determined in larger measure by what he does in processing or organizing the input signals.

Many experiments have shown that the process called the effort of search for meaning begins well in advance of stimulation. Often this is a "set", "meaning tendency" or "determining tendency" or a Harbartian "apperception mass" which often is set going by some form of instruction, quite often self-imposed and also quite often carried as an attitude, belief, purpose, desire, intention or a sentiment, which the British psychologist, A. F. Shand, defined as a generalized and abstracted systematic organization of rational and intellectual knowledge.

In visual training experience one repeatedly observes the blocking, defeatist attitude of the non-reader, who in almost every case shows you a pattern of weak, distorted space and form perception. A former student, Mr. B. R. Higley, recorded respiration, blood pressure and pulse, galvanic skin reaction in the resting state and then on asking his non-reading subjects to read aloud, obtained records which showed blocking even before the book was opened. It is clear that one of the things the successful trainer must do as early as possible is to replace this defeatist attitude with the self conviction that "It can be done and by the beard of the Phrophet, I can do it."

What is meant by the perceivors process of organizing his experiences and movements into a well-structured, unitary system of residual traces, capable of remaining relatively stable and invariant?

No one can question the fact that the colloidal emulsions of protoplasm can have hysteresis effects. These may be of the types like anaphylaxis, sensitization and immunization. If the myriad possible changes in molecular structure, say of the nuclear proteins of the brain cells are the vehicles of memory traces, then how can we recall events that occurred longer ago than the seven years which is said to be the length of time for complete metabolic replacement of the cell substance?

Professor Gerard in his Scientific American paper on "What is Memory" can find no satisfactory molecular or neurophysiological mechanisms for memory. So, the processes of trace aggregation and segration must be sought in some other set of functions.

The clue gained from the experiements seems clear and convincing. I show you a picture of a group of sunlit bushes with the light and shade pattern quite homogeneous and quite uniformly scattered or lacking in pattern organization. Half asleep beneath the bushes is a sprawling Tom cat. After due time and effort you discover his head and front feet. But it takes more searching to see his striped body. To disembed the figure from the ground, to make the figure salient, one must now disregard some "parts" or sub-regions of the total scene and give weight to other regions which begin to "belong" together.

"Belonging" here means precisely what Wertheimer called the laws of field structuring or organization, namely such things as proximity, similarity, good continuation, closure, common fate, etc.

Many years ago I had a fine laboratory course in cat anatomy, I made histological sections and drawings of about every tissue and organ in the cat's body. When I look at the picture described above, none of these things occur to me. My frame of reference is pictorial. I am looking for something which will fit my frame of reference at that time and which if I can see it will lead on to the consummatory phase of the process, which is that now I can classify and give a name to the figure and then go on to do something about it which fits my longer section schemata of behavior.

Tomorrow if I look again at the same picture I do not need to search out again those details which form the figure. The whole process characteristically is foreshortened. Recognition may be "instantaneous", that is to say the consummatory response we call understanding, classifying, naming, getting meaning, is now immediately triggered into activity without the necessity of going through the intermediate steps in the original process.

We have studied extensively over twenty-five years another phase of this process of organizing in perception. It is the process of grouping. Here are two boys, one age 12 who can reproduce correctly 86% of 9 digit numbers shown at 1/100 second; the other, age 21 and untrained, can only reproduce correctly 30% of 5 digit numbers.

What does the younger boy do which the older one cannot do?

Opposite to the cat disembedding function is the one of syncretism or synthesis - what William James called "thinking things together". The length and ease or difficulty in 9 digit numbers depends almost entirely upon one thing - the grouping schema. The younger boy by regular tachistoscopic practice sees 9 digits as two groups, either 5 and 4 or 6 and 3. Occasionally he tells me he gets a 9 as a single group, just like the long word RESTAURANT is as easy to see as the word CAT.

Grouping is a skill which is transposable. That is the function when properly trained becomes more and more independent of content. It is exemplified by the fact that a melody is perceived as the same regardless of the key in which it is played. Grouping words, phrases and finally sentences makes them unitary, coherent, internally structured to resist error and distortion. When one learns to group one kind of symbol or form, one can group other kinds with almost the same facility, provided the things are not culturally incompatible with the perceiver's behavior life history, i.e., the organized trace systems which dynamically forms before stimulation.

Knowing the correcting and maintaining role of the backstroke mechanism, it is thus evident why cheiroscopic tracing of forms while they are seen is so effective a means of articulating the visual impression with the mode of response which fits appropriately the course of action which is most expedient biologically and physiologically.

The organism in such a theoretical framework does not "store" specific patterns. Its behavior life is a continual process of redintegrating trace dynamic systems partly in terms of stimulus configurations, partly in terms of constantly reshaped "frames of reference", and partly in terms of autistic and social forces all integral to the self.

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PERCEPTION L

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Last month a very brief statement was made as to the role of schemata or frames of reference in visual form perception. These are very intricately organized organic processes, functions of the whole integrated person. When one says, for example, that "Bill is an honest man," there is implied the meaning that the probability is high that in his usual life activities Bill can be trusted to act according to the golden rule.

But under stresses of various kinds and intensities, honesty as an abstraction may reach a break point. Think of the famous story of Jean Valjean. Statements, like that of the late Elbert Hubbard, that "Morals are largely matters of geography," are only true if the frames of reference, standards, beliefs of the individual are dependent upon varying local conditions in space and time. This is only another way of indicating that our frames of reference vary widely in stability, resistance to change or degree of invariance. Sudden changes may take place in perfectly "normal" persons such as in conversions to sets of religious, scientific or artistic principles.

Sometimes these very complex sets, attitudes and beliefs are rooted essentially in "silent" processes, that is processes which are not open to our own introspective examinations and report. A shape or form may be beautiful or ugly, attractive or repellant, because it has physiognomic character. This is to say that the relation of the properties of the thing to the perceivors frame of reference reaches a stage of compatability or imcompatability so that the value or valence of the thing leads to classification and to action of some sort or other and meaning accures as a function of the consequential feedback to the closed organic field.

All human judgment takes essentially the same form. It is in fact the pattern of the paired-comparison in which something is judged in terms of something else. This "something else" may be a set of traces left in the active physical system and I shall try to point out that here is the important place where language and speech comes to play its highly important role in perception.

Speech and language - naming - is the distinctively human form of behavior. No other organism has such a mechanism. A man may be able to understand and so act upon a hundred thousand word symbols. And no other known function is as complex, in terms of the sensory-cerebromotor involvements.

In 1936 Granahan pointed out that language functions in perception "to make those features of the objective world that are the represented by linguistic forms stand out in greater articulation, to cause similarities to be seen in things similarly represented, and in general to influence perception in the direction of the speech forms."

While experimental evidence is not complete to show that we tend to perceive more readily that which we can name most easily, the weight of evidence points clearly in that direction.

But in the negative case we have clear cut evidence. This is exemplified in a picture by the late Charles Dana Gibson, which I show as a latern slide. When in short exposure and far out in the blur only a grey oval blob of light is seen, the observer begins his search for meaning, what can this be? Is it a so and so? And so on. The next exposure is then slightly sharpened in focus but still is not at all clear. Soon almost everyone names the figure "a skull." It looks uniformly white with black spots which "look like" or "could be" eyes, nostrils, teeth and mouth regions.

Once this linguistic naming has produced its set (to see a skull), it persists until almost complete and maximal clearness and sharpness of focus has been attained. Suddenly a point is reached and the viewers gasp in surprise. The picture is that of a young lady sitting at a dressing table in front of a large oval mirror. The row of cosmetic bottles, etc. were seen as teeth; and this was necessary in terms of the appurtenance or belongingness set in motion by naming or classifying. Thus the general, the whole is strongly determinative of the roles played by the various parts or sub-regions of the visual field. The final perception and its meaning are not a mere conjunction or setting together of more or less independent facts, but is an intricately organized system of size, form, brightness and other relations which will achieve as much of unity and coherence as the relation of the stimulus object out there to the highly intricate set of observer processes in here will permit.

Speech and hearing - language - thus is a large and highly important component in visual perception and often may and does determine the course of the processes and so their ultimate meaning.

I should like to emphasize here the fact that when we talk about "visual training" what we are basically and primarily concerned with is the reorganization of the perceiver's frames of reference and teaching him the art of the interpretation - in terms of understanding and action - of the stimulus object or objects. As one is trained beyond the shoulder of the curve, experiments made over a number of years have clearly indicated two things: (1) The truth of the law of the recession of the stimulus. This merely states that as one becomes more and more skilled in the art of visual perception, the role of the stimulus diminishes proportionately. Thus the trained perceiver depends less and less upon acuity or sharp resolution, contrast, illumination intensity, exposure time, etc. than does the untrained. And (2) as was developed from the experiments in this laboratory by Dr. Otis Knight, the trained perceiver replaces the old order functions which are loosely organized by a new and different and much more efficient and energy conserving system of functions.

Thus perception works exactly like any other type of manipulatory skill, in which the early untrained movements are tension movements, which on proper training are completely replaced by ballistic movements as skill approximates virtuosity. Training thus should never stop until such level of skill has been attained.

In the untrained perceiver exposures of 10 milliseconds enables the untrained perceiver to see forms in the stages of development of the process only up to the generic object stage. Brigden in 1933 and Schwarzbek and Knight with me during 1933-35 showed that longer exposures (1/2 - 2 sec.) actually decreased the accuracy of perception so that the unsuccessful effort to perceive more detail to develop further the specific object interfered with the next stage (of the generic object) with the end result that details as well as the broad outlines of the generic object were incapable of being reproduced. This is why we must train in exposures of not longer than .01 to .02 seconds.

Perception of forms - digits, stereo scenes and pictures of commonly known objects - can be perfect in exposures as short as two microseconds. Since this is so, it must follow that the function of the stimulus is a triggering one. It instigates processes already set to go. Figuratively, in perception the show is over before the curtain goes up.

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PSYCHOLOGICAL OPTICS

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PERCEPTION LI

August - 1956 Vol. 16 No. 5

Terms like schemata, memory traces, frames of reference, need some further clarification. This is not only because they play so important a role in perception but also because they are commonly misunderstood.

William James more than a half century ago wrote in the Principles of Psychology that "all the materials of our thought, and we may add, all acquirement of skill in movement, are due to the way in which one elementary process of the cerebral hemispheres tends to excite whatever other elementary process it may have excited at some former time."

The important part here is the last part of this quotation. It merely emphasizes the fact that to perceive and understand anything the immediate present experiential input has to be brought into some sort of dynamic interrelation with some residuum of previous experience, or with some symbolic projection into the future. In either case there is merely a recognition of the fact that experience does leave in the organic functional system something capable of serving as a transforming agent when the trace system is active in conjunction with the input from the sense organs.

It has been said that these organized trace systems are models of physical hysteresis effects, like the magnetizing arrangement of molecules in an iron rod. But like most alalogies it is dangerous to push it too far. We know from the experiments that traces are not stable but undergo continuous changes. This has been shown in many experiments on perception by Gestalt psychologists to be either a trend toward sharpening or leveling. The referential frame may figuratively 'feed upon itself' and assimilate to itself components which because of similarity of meaning or significance cause the system to enlarge. This is often seen in learning where if A and B have been learned, C may appear without any direct practice. This is especially seen in linguistics where if one has mastered English, Greek and Latin, the learning of another language, such as French, Spanish or Italian, is greatly facilitated.

Leveling of traces means simply that trace systems may become simpler or stereotyped and lose details, and so often increase the number of possible and probable instances in which they may by inductive inference, apply to wrong or erroneous conclusions. The logic of science contains many concrete instances of this, particularly in the appraisal of results of experiments in affirming or denying the validity of an hypothesis.

Simply stated, the interaction of the input in perception with the residual traces from previous experience is not a process of pouring some plastic substance into a fixed and rigid mold. Rather there is a complex set of dynamic interactions and these may either occur very quickly, that is in a few milliseconds, or may run a considerable course in time. But this is only a partial statement of the actual process of what is often called programming, encoding, assimilation, aggregation, or association.

Each is a name attached to the fact that something important - yes, very important, is contributed to perception when the incoming volleys activate the frontal regions of the brain. Each word is thus only a label and tells us nothing really about what actually takes place at this point in any true analysis of the total process.

Thus far there has been no mention of the mechanism which is the really important factor in the stage of the perceptual process in which coaction of input and trace finally extends to movement and meaning. This is the backstroke from the tonic, postural and phasic movement systems. If one by certain drugs, or by certain diseases or injuries weakens or abolishes the backstroke mechanism, one well known consequence is some degree of form blindness commensurate with the degree of reduction or insult to the pace-setting, maintaining and movement pattern determining role of the backstroke. No input and no memory trace can coact unless there has been integration of the functions within the framework of the organism's habitus in achieving the equilibrium or homeostasis demanded by the environmental demands upon the organism at the time.

Several years ago these papers proposed that the conative or action aspect of perception had been systematically neglected. That was a series on motor theory and its role in organic behavior.

Why does a child, or for that matter an untrained adult, do such a miserable job of trying to draw or reproduce the shape of some common object? How is it that a skilled artist or cartoonist with a few deft lines can show the essence, the salient characteristics of a person?

One does not see until the act of seeing is consummated in some sort of overt or implicit movement. This movement must be compatible and fit into the stream of adjustory processes directed to achieve what Le Chatelier's law specifies, namely an equilibrium state which conforms to the biological and psychological demands at the moment. Thus the stage is set anew and the perceiver is ready for the next behavior act.

Nowhere that I know is this stated more clearly than in the speech of the Play King in Act III, Scene II, of Hamlet:

Play King:
I do believe you think what now you speak;
But what we do determine oft we break.
Purpose is but the slave to memory;
Of violent birth, but poor validity:
Which now like fruit unripe, sticks on the tree;
But fall unshaken when they mellow be.
Most necessary 'tis that we forget,
To pay ourselves what to ourselves is debt:
What to ourselves in passion we propose,
The passion ending, doth the purpose lose.
The violence of either grief or joy
Their own enactures with themselves destroy:

How all important it is in training a person to see to integrate the movement system, to free the organism from the stress disjunction sets up, with the input from all the sense organs!

If you are set to see a 7 digit number tachistoscopically and you accidentally show an 8, the perceiver may record the first 7 correctly and stoutly deny the presence of the last digit. And if the 'accidental' showing is a 6 and he is set for a 7, he will more than likely write 7 and insist that he saw all 7. These cases are frequently observed. The pattern of action, set to go in the foreperiod, the period on instruction is a strong determinant of what any stimulus pattern does or can do in perception.

Suppose we look for a moment at another case. Suppose you wish to recall the name of the author of a scientific paper, which at the moment is very important to you, but which try as you will, escapes recall. Professor James in 1890 (psychology, Vol. 1, p. 251) astutely observed that in such cases if we "try to recall a forgotten name. The state of our consciousness is peculiar. There is a gap therein, but no more gap. It is a gap that is intensely active. A sort of wraith of the name is in it, beckoning us in a given direction, making us at moments tingle with a sense of our closeness, and then letting us sink back without the longed-for term. If wrong names are proposed to us, this singularly definite gap acts immediately so as to negate them. They do not fit into its mold. And the gap of one word does not feel like the gap of another . . . . The rhythm of a lost word may be there without a sound to clothe it; or the evanescent sense of something which is the initial vowel or consonant may mock us fitfully, without growing more distinct."

James saw the process at work - identical as to its form with any instance of problem solution or the search for meaning. This, reduced to its lowest terms, is a matter of appurtenance, belongingness, compatibility, similarity to the final name which fits all the motor ground organizations requisite and necessary to support the figure and form it into a unitary structure. It is a matter of grouping; of field organization. And it follows the principles seen in so many of the modern experiments on perception.

So, now you see why I insist upon the solid theoretical groundwork for adequate tachistoscopic form perception training. Grouping skill which is, in the last analysis, effected by the form of the executant motor processes becomes more and more independent of content. That is to say, it is transposable. And the most effective way we have found to expand and enlarge it, is through the motor rather than the sensory phase of the process.

If you question these facts, let me urge you to make a simple demonstration. Let us set the motor apparatus in advance and keep it ready to go in a specific pattern of movement. Set your lips, tongue, etc. as if you are ready to pronounce distinctly the vowel sound O (Oh!). Now have someone say to you "Do not move or change your vocal posture, but now think of the word ___". Here they pronounce to you words like lamp, water, house, father, etc. If you have obeyed instructions you will note that meaning vanishes at once. And that it requires effort, more than you are able to give often, to resist the movements to articulate subvocally the word pronounced to you. Seeing, that is signaling, is the first term in a series of processes, the end of which is some kind of movement which is in line with the organism - environment set of field forces. Stratton, Ewert, Peterson, Lanier, Pronko and Snyder and others have amply shown this to be true. In the competition of visual signals with motor processes of an adaptive character, vision transforms to fit the motor pattern, not the other way around.

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PERCEPTION LII

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Arguments were presented, in very abbreviated form, last month to show that perhaps the most important thing a child learns when he learns to see forms, sizes, positions, distances is the generalized skill in grouping. At any instant, the two eyes receive an amazingly complex set of sensory input signals varying from moment to moment in size, brightness, contrast, color, etc., and simultaneously patterns of sound, touch, kinaesthesis, organics, smell and taste, and all the incoming signals are correlated in the mid-brain. This was Von Hornbostel's principle of the "unity of the senses"; the argument that there is no such thing as vision, purely as vision alone. All you need to do to convince yourself of the soundness of this principle is to take acuities, phorias, etc., standing, sitting, reclining on your back or front and repeat under varying "white noise" and silence conditions, and note the differences.

We argued that the perception of things visually therefore was contingent upon the fundamentally important contributions to the total process of the effector or action systems of the body; that meaning is essentially kinaesthetic, conative and motor and that in the mechanism of the closed loop backstroke we have the pace setting, maintaining and unifying mechanism which is the paradigm of what we mean by grouping in perception.

There are many evidences supporting this position. As early as 1910 when Helmholz's Physiological Optics appeared, this great genius wrote (Vol. III, p. 260) "I ought to mention here an experience which I have often had, as follows. If I shut my eyes and hold up my forefinger, and try to focus it without opening my eyes, the moment I do open them I see double images of it; indicating that the lines of fixation are parallel or nearly so, and therefore pass by the finger about equally far from it on both sides. But in some strange fashion, with my eyes closed, I do contrive to get a clearer idea of the place where my finger is by touching the tip of it and rubbing it with the thumb of the same hand. Then indeed, even with eyelids closed, it is possible for me so to focus my eyes that the moment they are opened the finger is seen singly. It is the same way too when I touch and feel an external stationary object." Further, on the same page, he said: "Thus all stimulations of the fibers of the optic nerve are referred out in space, according to the law by which luminous phenomena are supposed to occur in those parts of the field (or of both fields), where material objects appear to be that are in such a position to send light to the corresponding places on the retina." This certainly was one of the first, if not the first expression of the principle of external reference. In its development Helmholtz took the position that "sensations", that is stimulus energy patterns and their attributes could not possibly explain with any degree of satisfaction our perceptions of objects, forms, sizes, positions, distances. One had to include, he held, the transforming effects of memory. And this could only exist by the activities he described as training and experience. The interpretations "by the intelligence" of the meaning of an excitation of the sense organs was, for him, also not possible by assuming that each sensory component was directly perceived and understood. For this, said he, would destroy unity and meaning, and no process of the mere conjoining of the assumed "separate elements" could possibly provide what in direct apprehension was accomplished by what he called the "unbewusster Schluss" or the unconscious conclusion.

We may say, for example, that this feminine face is beautiful, that one ugly; yet we cannot precisely report what it is or what set of stimulus relations makes one to be judged beautiful and one not so. Today we speak of such things as physiognomic characters. That is, we always perceive more than the mere aggregate of stimuli. As one follows the clear and keen descriptive analyses written on perception by Helmholtz (who died in 1894!) one is struck again and again by the very modern position he held at least 70 years earlier than our present day.

His position was of course diametrically opposed to that of Hering, who was a nativist; who held that what the eye sees is fully and completely understood if you have learned anatomy, physical optics and neurophysiology; and that seeing is only a function of the stimuli and their physical attributes. The Hering position is, strangely enough, the one held even today by most ophthamologists and optometrists and by many psychologists. It is doubtful if they ever met with any alternative during their training, for most of their education, we must simply face it, is undergraduate education. Needless to say Helmholtz's position at this early date met opposition. It still does. But so does the opposing position of Hering. Our concern is to look at all the available evidence, then formulate our own acceptable standpoint.

Strange as it may seem the early discovery of the biological role of the proprioceptors in the backstroke is probably as old as its physical or mechanical paradigm in the feed-back of the mechanical and electrical engineer. The "governor" of the old time steam engine was one of the early control mechanisms. If the engine started to race, the toggle through centrigugal force on the two weights, shut off some of the steam, and thus did part of the work of the engineer. From the word "governor" "steerer" or "helmsman" Professor Wiener coined from the Greek the English word cybernetics - the study of "automatic" feed-back mechanisms like the thermostat which "controls" your gas or oil furnace or the devices found in radio and television sets, in electronic computers, "automatic pilots" on airplanes, etc.

It was not long until Wiener, Von Neuman the mathematician, Turing in England, and particularly Claude Shannon of the Bell Telephone laboratories developed the ideas regarding the processes of communication which have come to be disignated as information theory.

Human thinking has moved forward in great strides by the process of substituting something easy, simple and short for something long, involved, difficult and so error prone. For example our language is like that. It is easy to remember a sentence of a dozen words or more and hard to remember the same number of unrelated words. It is easy to deal with a relation, such as the tangent of an angle and longer and more involved to say the side opposite the angle divided by the side adjacent. This by whatever name is grouping, because it originates when we discover how one thing is related to something else, or how things may be handled as a class or group and this given a name or symbol.

Shannon's interest was to inquire as to how to determine the amount of information that could be carried by any conducting communicative system using the shorter, more efficient coded signals.

The amount of information that can be carried per unit item, word, or symbol, he said, is the logarithm to the base 2 of the number of possible judgments, choices or responses. If I ask "Is it day or night?" or any such question, your answer can be yes or no, plus or minus, one or zero, on or off, open or closed, go or stop, etc. So whenever there are two and only two possible responses the information carried by a binary digit (say 1 for yes, 0 for no) is $\log_2 2 = 1$ bit, the word bit being coined from b-in binary and -it from digit, thus taken as one quantum of "information".

If we had a system of signals consisting of 8 shapes, say 8 levers with different shaped knobs, each knob could carry 3 bits of information since $\log_2 8 = 3$. In the 26 letters of the alphabet we use, each letter can have, thus, $\log_2 26$ or 4.7 bits.

Codes or symbols can, if properly selected, carry much information. There are endless illustrations of this entirely independent of information theory. For example I have been interested for several years in quantitative measurements of the visual size - distance relation. If I show you a square 30 x 30 cm. at a distance of three meters and ask you to tell me how big it looks to you be selecting another square which just matches it in area, then if I move the square to 6, 12, 24, 48 and 96 meters and you match at each point, looking at stereos of the square at far point in a Disparator, I may wish to know, as the matches grow smaller and smaller with increased distance, "What is the rate of change of the rate of change, under these conditions?"

What I am asking mathematically is: what is the second differential of size with respect to distance? Computing the data of the experiment, I find this to be $\frac{d^2y}{dx^2} = + \frac{.9030}{x^2}$. To anyone who understands, or reads, this kind of language it means merely that as you move out from 3 to 96 meters the Area or Size of the perceived squares diminishes rapidly at first, then slows down more and more, with only a small change taking place between the 48 and 96 meter distances. A little group of symbols can tell a lot - can carry a lot of information, provided of course that the receiver has learned to understand the signaling system.

In the brief space of this paper one can only sketch the meaning of information theory very incompletely. Are the bits of information or input signals things which are combined or foreshortened by some coding process in the brain; and is there a definite limit as to the number of such bits a nerve can carry without overloading? Can grouping skill be developed and expanded by training, and if so what are the limits?

The important thing, it seems to me, is that scientists are seeking new approaches, new concepts, new mechanisms, all involving the problems of how we perceive, learn, remember and solve problems. In a recent book by Shannon and McCarthy (Automata Studies) part of one section by Professor Ashby is entitled "Design for an Intelligence Amplifier". Possibly Mr. Kettering, one of our distinguished Alumni, was right when he said that the impossible problem is the one that hasn't been worked on.

Next month we shall take a further look at grouping, and consider some of the potentials of the information approach to the problems of visual perception.

(This Paper Completes Volume 16)

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PERCEPTION: LIII

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Last month a brief statement was made to give a very sketchy statement as to the meaning of information theory. This originated with Claude Shannon of the Bell Telephone laboratories. From its early development from problems arising in modern electrical communication systems, where transistors, and such inventions, make possible many messages traveling simultaneously over the same conductor and with the wave forms of speech and hearing transformed and often scrambled and inverted in transmission, and then rearranged at the receiving end, it is natural, logical and in fact inescapable that information theory had to be extended into the problems of experimental psychology, or as some elect to speak of it, of "human engineering".

For those interested in the subject, a recent book Information Theory in Psychology by Henry Quarstler (The Free Press, Glencoe, Ill.) will help to show some of the problems and procedures involved in the treatment of the mathematical and mechanical models which, after all, are basically and fundamentally problems of human perception.

Suppose we placed the capital letter A on a sheet of white paper. A small scanning beam of light is passed from left to right across the sheet and another alternatively from right to left, each making 500 sweeps per second. As the light bounces back from the paper, it activates a small photo-sensitive cell and this ceases when the light hits the black absorbing ink of the top of the A. As it moves downward the bips get farther apart and the off-phase lasts much longer, of course, through the central crossbar of the A.

These electrical input impulses can be made to magnetize a tape, storing them in "memory" as it were, and is so done in some complex computer type instruments where the input signals can be combined or grouped or encoded. This scanning or detector device may, in the simplest case, be of the binary on-off type and so the system can be treated in terms of probabilities of the bits of information of Shannon's theory. Or the input potentials can be arranged to be recorded in an intensity continuum to produce a representative image such as we see on the black-white television screen.

The input is thus not a fixed pattern or image which precisely copies the thing or object scanned or seen, but is a transformed signal which can be made to redintegrate the meaningful experiences as if our eyes, ears, brain and effectors were operating as they do in everyday life.

According to Craik, when we see, we are getting about 10 snapshots per second. The receptors convert light into volleys of virtually transferred, weak and relatively slow moving electro-chemical energy. In a previous paper of this series a diagram, adopted from the work of McCulloch, attempted to show how in the brain these volleys of afferent impulses move about from place to place in order that when "programmed" they may trigger off an appropriate movement a series of movements the backstroke from which is an absolute essential to any meaningful understanding.

Input signals never come into the central distributor mechanism (brain and cord) as upon a blank page. Even from the earliest development of gradients or structures in foetal life the very fact of biological life and the structuring of the organism means that the potencies and probabilities of specific behavior forms can be attributed only in part to the intensity, duration, area, frequency, etc., of the input signals. The law of "the recession of the stimulus" means simply that with increased training and experience the role played by the stimulus signal as a determinant becomes less and less. The trained perceiver uses operations as different from those of the untrained as the virtuoso with his smooth, effortless ballistic movements differs from the wasteful, erratic tension movements of the novice.

It is interesting to speculate what a perfect man or woman would be like. One, let us say, with an IQ of 400! One who could read 6000 words per minute with 100% understanding; one who could invent and solve problems baffling to most of us "as easy as pie". How would such a God-like person handle his input information? Would he be hopelessly bored and only wish for an escape from the monotony or would he live in an eager world, perceptually, of scheming up new devices, new answers to the questions which leave us stymied?

Regardless of the answers you may elect to give to such questions, we must face the fact that the oldest problem in psychology, the one which started us in our pilgrimage along the road of science, is still today perhaps our newest and most important problem.

I refer to the fundamental concepts of psychophysics - the problem of the relations of the magnitudes of the energy changes from the impact energies picked up by our physical detectors or sense organs and the perceptual, experiential or phenomenal discriminations we are able to make to them. Many years ago Titchener wrote that we always perceive more than is furnished by stimulus. Every input signal thus overlays kinetic, on-going processes, many of them carried as "silent" processes, ones of which we are not consciously aware. These are beliefs, sentiments, sets, attitudes, prejudices, biases.

Here information theory, as well as other psychophysical theories meet a dilemma. I refer to what psychologists call the phi-gamma hypothesis. Phi refers to the physical continuum and gamma is the code or symbol for the perceptual, cognitive or understanding realm of experience.

Stated more precisely the phi-gamma hypothesis states that if we wish to determine a stimulus limen or threshold or a difference limen using any precise psychometric method, the relation of the proportion of observer responses of yes-no to increasing stimulus intensities is accurately described by the integral of the normal or Gaussian probability curve.

This, of course, suggests the problem of the distinction, if there is a distinction, between the eminently respectable operations of the insurance actuary and his business, and that of the gambler; the real difference, if such there be, between the farmer who bets $2 on the nose of a horse at the race track one day and the next day plants his seed in the soil and hopes for an eventual profitable crop later on.

Credited with being the first to study the problem of the relation of physical stimulus intensity and phenomenal or discriminal intensity was Ernst Heinrich Wever (1795-1878) a professor of anatomy and later of physiology at Leipzig. He published in 1834 a monograph on touch sensitivity and in 1846, Der Tastsinn und das Gemeingefuhl.

Then on October 22, 1850, G. T. Fechner proposed that an arithmetic series in intensities (i. e. discriminations) might correspond to a geometric series of physical energies, and that a given absolute increase of intensity might depend upon the ratio of the increase of bodily force to the total force. Ten years later (1860) he published the Elementc der Psychophysik - an "exact science of the functional relations of dependency between body and mind."

Weber proposed that $\frac{\Delta I}{I} = k$, that the amount you have to add to any stimulus will be a constant. If k = .05 for lifting a weight of 40 grams, then a 42 gram weight will be perceived as just perceptibly heavier exactly half of the times you lift and compare them. And if k is constant, it will require 4 grams added to make an 84 seem just heavier than a standard 80 gram weight.

Fechner integrated the series into a fundamental formula: $S = k \log R$, where S was the sensory intensity, K the Weber constant, and R stood for reiz, the German word for stimulus.

The integral of the bell shaped or "normal" probability curve is an ogive or S shaped curve and represents the Fechnerian ratio of added physical energies to the number of judgments "greater than". Such theorizing assumes that light, sound, touch, etc., produce in the nerve conductors unit quanta which in terms of the all-or-none principle insists that how much we discriminate must be due to how many quanta of energy are produced by the stimulus.

But as is often the case, a nice, logical theory, "just around the corner" meets evidence from carefully made experiments which do not fit.

Next time we shall take a look at some non-quantal facts, and then later on see if we can work out a defensible summary statement.

It is not easy thus to define rigorously intensity (as we commonly use the term), just as it is troublesome to make a rigorous definition of a similar word - Stimulus - which those who know it most, know it least.

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195

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PERCEPTION LIV

November - 1956

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The problem of psychophysics, that is of the relation of the energy of the physical stimulus to the quantal magnitude of the resulting discrimination was introduced in our preceding paper. It has been pointed out in these papers previously that as the physical continuum, i.e., the stimulus, increases in equal steps of intensity, our discriminations do not increase in the same ratio. As physical intensity grows incrementally we must go some distance on the physical scale before there is a sudden jump upward in the stair-step like discriminal series. This is merely to state the fact that as the physical stimulus increases in intensity at a constant rate, discriminations do not increase constantly, but wait until enough stimulus energy has increased to produce step-wise increments in our awareness that a light is just perceptibly brighter, a tone is just louder, etc. All of which is a restatement of the fact that to produce equal increments of brightness or loudness, for example, in a series of arithmetical steps representing just perceptible increases (or decreases) in perceived intensity, we must use a geometric series of stimulus intensities.

We can represent this roughly in two parallel columns. At the top is an equal series of just noticeable differences in brightness:

1 2 3 4 5 6 7

Below this we must increase the physical stimulus to produce this effect in the series:

1 2 4 8 16 32 64

This merely says that the more you have of anything, the more you have to add to make a just perceptible difference. This is the oldest problem in scientific psychology. It is not completely settled today.

One of the chief reasons for this situation is historical. What was more natural than to look to the theorems and methods of the older established divisions of science for the answers. Thus the answers were said to be found in the antecedents--that is in properties of the physical stimuli, such as size, brightness, duration, etc.

Clearly, here was an attempt, admittedly sincere and honest, to settle the problem, which is purely a psychological problem, by an appeal to physics, neurology and mathematical statistics. To measure anything you have to have an end point, origin, or zero. And it is evident that as you multiply observations you have to summate and generalize from these observations. Thus many competent scholars refused to grant that psychological problems could be solved eventually either by physical or physiological or mathematical means but must be solved psychologically. A great forward step was taken in 1912 by Professor Max Wertheimer. In a hundred page monograph he detailed his own extensive studies on the phenomena of visual apparent movement. His observers saw motion where there were no moving stimuli. Wertheimer said we must take an entirely different approach to the problem. We must not continue to seek for a non-existent constancy of relations between stimuli and discriminations or responses. The nervous system is a signalling system, not a power transmitting mechanism. Widely varying meanings or responses may hence be triggered off by the same signal or stimulus. The relation is therefore a dynamic relational one. Processes in the nervous or signal system are molecular processes--low potential, slow moving, virtual transfers of ions in the material medium. But discriminations, meanings, perceptions, actions are molar processes; they are acts of whole organisms, transformed molecular signals reorganized and directed into muscle and gland patterns which fit as conditions best permit at the time the behavior life of the organism: Thus he said we must think not of molecular and molar processes as two distinct and different things. The physiological processes in sense organs, nerve and brain must, he said, be regarded not as molecular processes but as integral and earlier phases of the molar phenomenon.

Köhler in 1920 put it this way: "Isomorphism, a term implying equality of form, makes the bold assumption that the motions of the atoms and molecules of the brain are not fundamentally different from thoughts and feelings, but in their molar aspects, considered as processes in extension, identical."

This is to say psychological problems--how we see forms, motion, sizes, distances, etc.,--can best be handled by psychological concepts and methods. Physiology, physics, and statistics may help but only secondarily. And, are they not achievements by many human beings operating as sensable, rational, discriminating and creating organisms?

It is only a step, and really a short one, in our thinking to see that the grouping, syncretic organization of the volleys of input signals is a transitive, active process which in most cases of adult life has already put on habits, attitudes and determining tendencies which practically certify what the organism will do or understand well in advance of the sensory input.

With these things in mind let us now return to our fundamental problem of psychophysics. Serious efforts to account for the step-wise series of discriminations following continuous stimulus intensity increments in terms of molecular processes in the nervous system, particularly in the brain, are currently being made. These efforts are made by highly competent scholars and I wish it clearly understood that while my present understanding and point of view differs from them, this means nothing and does not detract one iota from my respect for their competency as scholars and scientists.

Their efforts are spoken of as the neural quantum theory of intensity discrimination. At this point it is necessary to point out that the term quantum as applied to nervous processes is a radically different thing from the quantum of Planck in physics. There is a quantum of the smallest possible unit packet of energy, such as one photon of light. Here a neural quantum means the aggregate of molecular nervous processes which will just produce a discrimination or awareness of the stimulus barely above threshold. Thus a quantum is a functional concept since it does not mean a fixed number of neurons or length or complication of conduction pathways. It is defined in terms of the fact that a process of discrimination or awareness follows which is just above the lower limit of a threshold range. Thus in reality one must face the fact that it is not easy to decide whether a "neural quantum" represents a perceptual or a purely physical unit. My own notion is that, as indicated above, a neural quantum is some amount of electro-chemical energy in the central nervous mechanism; the existence of which is finally confirmed perceptually.

If this is the case, then above the lower limit of the stimulus threshold the problem becomes one of experimentally and statistically determining the number of quanta required to be added in order to produce each additional J.N.D. (just noticeable difference).

It must be evident that this at once takes us into some fairly deep water, since only expert investigations, using the most rigorous precision methods at their disposal, can hope to be able to offer substantial and substantiable proofs.

Logic is a funny business. If we accept the principle of isomorphism then it is difficult to see how we can operate in terms of the dualism of the physical, brain processes and identify them with the molar perceptual processes, unless we do as did Wertheimer and say they are both phases of one single process.

And even if we take the molecular processes as fundamental and measure and describe them by even the most delicate and precise electronic recorders, we can then only seek to discover to what extent we can identify pattern distributions of energy in the brain with reports of observer experiences.

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PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshow, Ph.D. at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PERCEPTION LV

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Before returning to the problem of the neural quantum theory and the evidence for it and opposed to it, and to some further exposition of modern "information" theory, it is first necessary to examine more in detail some of the fundamentals of psychophysics.

If one asks "What do you mean by psychophysics?" the ready answer you often get is: it is that province of experimental psychology which deals with the measurement of intensity, and of likenesses and differences of intensity. But this kind of statement defines nothing and gives us nothing more than an empty formula of words. The next logical question is: "Sure, but what do you mean by intensity?"

Here you can get one or more of several kinds of answers. The oldest answer, and one used by many who are untrained in experimental psychology, its methods and theoretical framework, is that intensity means merely and clearly the amount of energy of a physical stimulus "out there" which can act upon some receptor organ. This of course implies that the primary emphasis is upon the distal stimulus, and that intensity (along with duration, extensity, quality and other special attributes) is an intrinsic property of the physical energy coming from the object "out there". Stevens, for example, says that the problem of psychophysics is "the definition of the stimulus."

But, at once, if you subscribe to this kind of thinking, you are in trouble. These "attributive properties of the stimulus" assumed to be separate and independent, are not so. If hue is a special attribute of colored light and you change brightness, you not only change hue, but you also change saturation. Change brightness and contrast of an object in its surroundings and you find that you also change apparent size and distance. If a tone of a certain pitch frequency is made louder, the apparent or perceived pitch changes. The decibel is not a unit of loudness but of the pressure per unit area on the surface of the ear drum.

The problem of just what the attributes of the physical stimulus are and how they are interrelated has not as yet been satisfactorily settled. And while we agree that we must have accurate measures of the energies which impinge upon the receptor organs, we must insist that physical measurements of such moments of energy do not and cannot be the problem of psychophysics. When light reaches the retinas, Hecht showed that not more than 8 to 12 percent of the light energy is reflected off from the corneas, front and back surfaces of the lenses; some is absorbed in the media, etc. And only about 20 percent of the photoreceptors fire throughout the period of stimulation, if this is larger than about 1/10 second. This is a radical transformation by the sense organs of the input energy and somewhere in this series of events the distal becomes the proximal stimulus. Even if the lens could produce a dispersion of light as an exact replica of the object out there (i.e., a retinal image) only about 1/5 of the photocells, according to Hartline, fire throughout the period of excitation, so that under such conditions it is impossible to understand how the successive volleys of weak, slow-moving electro-chemical energy in the optic bundle could be any remotely similar kind of pattern resembling the original object. Then in the afferent course of events, as Adrian has pointed out, all incoming impulses from all the sense organs are correlated in the relaying stations of the mid-brain and these do not differ in any discovered characteristic. The incoming nervous processes from hearing, the skin, etc. are the same kinds of waves of energy as those from the eyes. Thus there can be no such thing as visual afferent volleys of virtually transferred ions (i.e. "nerve currents") in sinusoidal wave forms without the modulation, dampening, reinforcing, etc. going on amongst all the impulses coming in at any instant from all the modalities.

And, further, if it is assumed that by the time these impulses reach the cortex we are aware of the distal stimulus object mediated by the intervening processes, we can only understand this if through the principle of syncretism two additional things are written into the equation: (1) The effectors must be in the closed loop circuit; they must be in a state of tonus greater than a certain minimum; and (2) The entire sum of afferent nervous processes must co-act and inter-act with systems of "memory traces" which form the essential referential frames which give (with (1) above) meaning to the perception of the object "out there". The perceiver does something about this energy impact. It upsets an equilibrium and he sets about the restoration of some suitable and satisfactory new balance. So that it is clear that if one thinks and operates, to quote Tichener, with "the world with man left in", psychophysical intensity is an elaborately complicated set of processes in which a perceiver has to become aware of what is out there, and how much. This is a matter of the fundamental psychological pattern of a judgment. It is the referring, comparison and organization of the incoming and temporally new portions of the field to the residual frames of reference carried as memories, sentiments, beliefs, attitudes, purposes, desires, hopes, fears, etc., All of which eventually and often instantly shakes down to a consummatory state which we call naming, judging, perceiving, evaluating, scaling, etc.

It is the contention of the writer that the molar and the molecular portions of this whole process are one and the same. They are merely phases of or episodes in one continuous set of functions. Thus the real problem of psychophysics is, very broadly conceived, what are the determinants of a human judgment?

In such a concept, quality and quantity must be regarded as interdependent phases of the same reality and not as two separate and independent things.

Quantum theorists in psychophysics define a quantum not as Planck did in physics, Selig Hecht in vision or Gabor in sound intensity. Each of these defined a quantum in terms of a minimal unit of physical energy. A quantum in the neurophysiological approach to psychophysics refers to "a functionally distinct unit in the neural mechanisms which mediate sensory experience."

Such a definition postulates that as the "stimulus energy" increases beyond the threshold points on the scale a limit will be reached which produces a just discriminable increment of "sensory experience." That is to say another quantum (cell assembly?) has now been added to "the neural mechanisms which mediate sensory experience."

Nowhere is there the barest hint that the effectors have any part to play whatsoever in the process. Yet we know that without the feedback from them there can be no awareness. As Hudson Hoagland has brilliantly shown, the feedback is the pacemaker, the agent which sets the vectors of behavior and unifies and coordinates the system into, for example, a voluntary skilled movement.

If one doubts these facts let him ponder a paper written by a friend and former student on "The Influence of Occupation on the Perception of Time." (H. Gulliksen, J. Exper. Psychol., 1927, 10, 52 ff.). Later I shall present experimental evidence to show that as Richard Blackwell puts it "quantum theorists have so restricted the allowable conditions of measurement and the analysis of data that it is difficult to obtain an unambiguous evaluation of the theory."

In all considerations of psychophysics we have to devise scales of measurement. The basic essential for devising a measuring scale is the recognition of groups. In mathematics a group is a set of operations. In experimental psychology it is the same. For example, if I show you tachistoscopically for 10 milliseconds a number containing 9 digits like 2 1 4 9 2 1 9 5 6 I may see and so reproduce this as 214-921-956, thus I transform 9 simple digits "out there" into three groups of 3 digits each. But if another person sees this number as 2-1492-1956 he also has 3 groups, but the group assemblies are now different and the time and energy in the segregation and re-aggregation into groups will be less. The limiting case is one where, if we train sufficiently, the 9 digit number becomes a single unity in perception just as the word FRUGALITY is seen as a single word or thing and takes no longer or no more energy to see than does the word DOG. Cattell many years ago at Columbia University showed that the *O* standing alone was harder to see than the same *O* in DOG.

In grouping Professor Stevens puts it this way: "One operation followed by another operation produces a result that is the same as what could have been produced by one or more different operations."

In baseball, for example, the manager to increase his chance of winning "shakes up" his batting order. He now puts the lead-off man in the 4th or "clean up" position by interchanging 1 and 2, then 2 and 3, then 3 and 4 which would put the lead-off man in the 4th place. Then to move the clean up man (now in 3rd place) to first place, he would interchange 3 and 2, then 2 and 1. These 5 "one for one" substitutions produce the same batting order that would have resulted had the manager interchanged 1 and 4 in the first place. If all nine men were changed so that all possible batting orders were obtained by changing 1 and 2, 1 and 3, 1 and 4, etc. and 2 and 1, 2 and 3, 2 and 4, etc., the number of possible orders is factorial *n* divided by 2, which turns out to be 362,880 different batting orders. From the above it is evident that "Some combinations of operations are equivalent to other combinations of operations."

Arrangements or combinations of things are called permutation groups. In tastework an organic substance is pictured as a benzine ring. If one changes the position of one atom in the molecule, although the substance is chemically the same, its taste may change from bitter to tasteless. The Bohr atomic structure is another kind of permutation group.

To set up the classification of a group the set of operations must fulfill or meet certain demands as to the operations, that is how the group members co-act and interact with one another, whether the ratios are invariant, etc. That is to say our operations now are the kinds dealt with in projective geometry, Boolian algebra and topology. I mention these things merely to show that groups form the basis for the making of scales.

Generally four kinds of scales may be set up for intensity measurement and description. In a horse race six animals are lined up at the starting gate. They bear numbers 3, 9, 1, 12, 5, and 4. The numbers mean only that they may be identified, and that at that place and time they are equal. This is called a *nominal* scale.

The second type is an *ordinal* scale. Here relative amounts of something is the operation determining scale position. Five girls are judged for Queen of something or other. The pooled ratings rank them

A	E	C	D	B.
1.0	2.5	2.5	4	5

E and C are thus tied for 2 or 3 positions. The ranking does not tell how much A is superior to E and C.

The third is the *interval* scale. Here the problem is to establish equality of intervals or differences. In a centegrade temperature scale freezing is at 0° and boiling at 100°. The room air here is now 21°C. Standard scores on achievement tests are illustrations since they are conversions to the scale of deviations above or below the mean of a large distribution.

Finally there are *ratio* scales, in which the scale is one of equal ratios. An example may be found in music where the fifth, c - g, relation is the same in each octave in terms of unit *mels* produced by the same ratios of different pitches or frequencies of the two tones.

Finally I should add that all scales are not continuous. Sometimes continuous increments may produce qualitative breaks, as the changes in color between wave lengths 400 to 700 millimicrons.

Next month we shall talk about methodology of measurement with some comments on psychophysics in relation to optometry.

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PSYCHOLOGICAL OPTICS

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There is a saying that "familiarity breeds contempt." The things we all have about us and use every day diminish in our valuation of them. Almost all who have eyes and can see can truthfully be said to have little appreciation of the matter of our intensity discrimination capacities for light and color.

What is the smallest amount of light energy that will be detected by the eye? Hecht, Schlaer and Pirenne studied this problem and made exacting measures of it. They pointed out that if I drop a green pea one inch on a glass plate, the mechanical energy of the fall, if transformed into light energy, "would be sufficient to give a faint impression of light to every man that ever lived."

From the lowest perceptible brightness to the maximal tolerable brightness the range of light intensities is very great. The stimulus threshold, namely that intensity of light which will produce a just perceptible discrimination of the presence of light in the visual field, in the foveal dark-adapted eye is about 0.275 microwatt per square meter of illuminated surface. A microwatt is one millionth of a watt. One watt (the electrical unit of power which is volts times amperes) is wqual to 10 million ergs of energy per second. An erg is approximately the energy required to raise a gram weight a distance of one hundredth of a millimeter against gravity. In the periphery the threshold is about one thousandth of the value for the macular region.

The above facts refer to stimuli of fairly large area. Small point sources, such as stars, show even more strikingly the sensitivity of the retina. To quote Professor Boring "The power of a faint star, visible in peripheral vision is about 10^{-8} microwatt (100 million millionths of a watt or one thousand millionth of an erg per second). Such a star would have to shine on the retina for forty years to deliver an erg of energy to it. If it can be perceived in a fifth of a second, then the retina is some 30,000 times as sensitive as the most sensitive radiometer which the physicists use to measure radiant energy."

From the standpoint of intensity the retinas are thus a very delicate set of weighing machines. From the standpoint of perception, how many discriminable steps or differences of brightness can be discriminated in the achromatic series from white through the grays to black?

The number of just perceptibly different steps from white to black under 20 apparent footcandles varies with different observers from about 160 to 350 steps, with the average at about 210. Within the range, Fechner in 1858, discovered that the ratio $\frac{\Delta I}{I}$ (the Weber fraction) was approximately constant. The value in vision of $\frac{\Delta I}{I}$ was found to be approximately 0.01. Within the range of white to black, that is to say, if you add to or diminish the luminous intensity by 1% you will be able half the time to perceive that the light is just noticeably stronger or weaker.

These considerations are mentioned here because in our discussion of intensity as a process and its measurement, in the year 1957, which is 123 years after Weber made the first discovery that human judgments of intensive differences showed ratios that were invariant, except at the extremes of the intensity range, and that these values integrated into the generalized "massformel" or psychophysical law by Fechner seemed to be capable of being regarded as a special case of the general principle of inertia in physics.

But in the last century an enormous amount of work and thought has been given to the problem of intensity and its measurement. One grave mistake, not only by the early workers but by far too many moderns, it seems to some of us, was the too narrow conception of the nature of the real problem. To measure thresholds, they held, you arranged control of the physical stimuli, increasing or decreasing them by constant amounts; you instructed the observer as to what he was to report in making his judgments; and you recorded these and then treated the data statistically to get values for means, distribution, variances, etc. The observer was a passive, secondarily important or relatively unimportant intervention between stimulus and response. And if observers differed from one another this difference was treated as an error function--something violating the ideal that the whole marvelous biological-chemical-psychological person should make judgments like any simple mechanical system always completely described in terms of the input-output energy ratios. Psychophysics of this sort was essentially physics--"the world with man left out". As psychologists became better trained a great many could not accept such a treatment of the problem, basic theory, methodology and handling of the data of intensity and its measurement. These men and women recognized that in vertebrate animals the higher the cultural status the greater is the influence, on any process of judging, of the trace systems, memory fields, frames of reference, physiognomic characters. Response to stimulation was not response to stimulation but something much more complicated. The complication was the contribution of the observer, a person, a highly organized system of beliefs, sentiments or rational standards, of form, space-time, autistic or social and moral values, etc., all unified under laws of organization, gradients, dominance and isolation of structural and functional anatomical regions and psychological ones. The observer transforms the stimulus signal into the proximal stimulus, which in turn enters into the dynamic processes of inter-action with the residual traces in the cerebro-motor system left by earlier training, experiences, bias, etc. and the ultimate judgment must therefore be affected to some greater or lesser degree by the same processes that occur in any perceptual act.

Suppose we are making a psychophysical experiment using lifted weights. We have a standard weight of 40 grams, and a comparison weight of 39 grams. If we ask the observer to lift the standard then the comparison weight and the comparison is judged heavier than the standard, this is called a negative time error. If the order is reversed and the comparison weight is lifted first and the standard is judged lighter, this is a positive time error. The judgment of the observer is thus affected by the order or sequence in time of the two stimuli. Köhler, for instance, found that in judging the intensity of tones he got a positive time error if the interval between the two tones was 1.5 seconds; practically no error at 3 seconds, and a negative error if the interval was 6-12 seconds.

It is not our purpose here to discuss the theories which have been proposed to account for these results, but merely to show that the operations of the observer, as was brought out in the preceding paper, determines the scale positions to which the observer ascribes the two stimuli.

Now let us look at another fact. Suppose that our observer has just carried several pairs of heavy suitcases up the four flights of stairs leading to the laboratory. We do not know this, and so seat him before a cubic screen and ask him to judge as before "Is the second weight heavier than the first?" He answers yes or no. We record say 50 such judgments. The mean and standard deviation of the distribution of his judgments are quite different from those he made on the same series of weights two days before when he came to the laboratory only having to walk up the stairs. Lifting the heavy suitcase made the weights both seem much lighter so that his scale of perceptual or apparent weights shifted to the left; this is called adaptation level. It is a determinant of any psychophysical measurement we make.

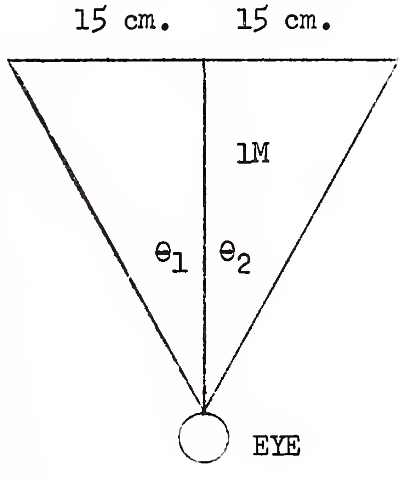
Suppose again I present to an observer

two pieces of 2 x 4 lumber one 8 inches tall and another 4 inches tall, both weighing the same number of grams. If he lifts them while looking at them he will insist that the shorter one is heavier. This has been called the size-weight illusion. It is a case where vision sets the stage and the kinaesthetic factor is made to fit the set or expectancy which is ongoing temporally before any lifting is done.

Then again, for many years it has been recognized that the summation of small part processes do not equal the equivalent intensity of the sum of such parts. You cannot add any number of pinks to produce red. That is merely to say that caution must be used in scaling or measuring because you may be tempted to add things which are not addable.

Displacements in binocular space inward and outward may be termed esophoria and exophoria. Operationally they are not members of a single continuum and if you proceed to add them algebraically or even to say that 8Δ exo is two times as much as 4Δ exo, you will be very wrong.

Suppose we have a target which is a 30 cm. square placed one meter in front of the eye. What angle does the target subtend at the eye? Let us illustrate:



The tangent of angle θ, is 15/100 or 0.15 or approximately 8° 32'. Since there are two equal triangles logic says that the tangent of the whole angle at the eye will be twice the half angle. But this is not true. $\tan. \theta_1 + \tan. \theta_2 = \frac{2\tan. \theta_1}{1-\tan.^2 \theta_1}$. and the difference will not be constant for all angle sizes. Wholes may be more than the sum of the sub-parts.

I once heard a "bright" young man (an optometrist, by the way!) criticize the analytical refractive examination on the ground that the measurements were not done by scientific psychophysical methods. Two things are wrong with such a position. Your patients are untrained observers and to obtain any measure meeting rigorous statistical demands, would mean for any single measure about 60 hours over 3 months of laborious effort. How long the entire 21 tests would take, I have no notion, but it would not be profitable. Second, the words tests in the last sentence is used advisedly. The tests used, as I have observed them, are "prob bodies" or detector devices designed only for the purpose of permitting a trained professional person to bring together information on groups of functions in order to decide what must be done about them. So such criticism is only the revelation of the critics lack of understanding of the real nature of psychophysics and simply does not and cannot apply to any refractive examination. No set of precise physical measurements of a complex set of field forces can tell the whole story. Anthropometry, brightness, color, etc. could be taken on Miss America, surely, but would they, by any form of combination, tell you that she is 5% more beautiful than her nearest competitor? I do not believe it.

Methodology is quite important in any discussion of quantitative experimental psychology. Let us look at that problem next.

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In Goethe's famous Chorus Mystacus the first two lines state that:

"Alles Vergängliche
Ist nur ein Gleichniss;..."

In English:

"All knowings
is only a similarity;..."

In psychophysics we deal with quantitative magnitudes of things, such as brightness, weights, sounds, distances, sizes, aesthetic values, colors, etc. The fundamental process is the pattern of the comparative judgment. When something is presented to us, say two spots of light, and these are seen either simultaneously or successively, and we are asked the question, "Is the second spot brighter than the first one"? we make the judgment by comparing the second with the first in terms of the positive or negative similarity of the two with respect to brightness independent of any other consideration, such as size, position, form, etc.

All "knowing" is thus a matter of the perception of some sort of relation, some degree of similarity of some attributive property of things or processes. In some cases we must utilize a method of absolute impression. Here, for example, we compare something presented to the sense organs not with something belonging to the same class of things or processes, but to some standard carried by the memory trace system. In a previous paper I pointed out that in vertebrate animals, especially humans, the higher the cultural status the greater is the influence of the frames of reference carried as memory traces and the less the determining influence of the stimulus in the kind of discriminatory responses that will follow any stimulus. This is essentially what is meant when we speak of a trained observer. The trained observer behaves differently in judging identities and differences than the untrained. His standard is much less variable; much less susceptible to error fluctuations than the untrained. If we ask him to make several hundred judgments to determine threshold limits and we plot these as a distribution curve we can then compute the standard deviation (root mean square deviation from the mean) of the distribution, designated σ dis. The measure of precision of his judgments, h, is then given by

$$h = \frac{1}{\sigma\sqrt{2}}$$

and $$h = \frac{.707107}{\sigma}$$

and so $$\sigma = \frac{.707107}{h}$$

Thus we calibrate the observer in essentially the same way we calibrate any precision instrument. A fine watch may gain or lose two seconds in twenty-four hours. For some purposes this is not good enough. It all depends on what our problem is, or what we are attempting to do. So with the observer. He will vary from day to day or within different times of the same day. Skill in doing careful psychophysical work as an experimenter consists in knowing and recognizing all the agents which can and do influence the observers judgments and controlling them as precisely as possible.

Often we are concerned with thresholds. A threshold is a break point. Suppose we dark adapt an observer for 30 minutes and seat him before a 6 foot square screen in very low illumination and with scale numbers from 1 to 100 on the left and bottom (ordinate and abscissa) of the screen. The observer is instructed to report the coordinate position of a spot of light 25 mm. in diameter which is just intense or bright enough to be seen half of the time. The light is "on" for 1 second after a warning signal "Ready" and 2 seconds later "Now", and 2 seconds later the light is on for 1 second then off for 10 or more seconds.

It is obvious that if we start at a very low point on the physical continuum of light and each successive time show a light which is brighter by a small but constant amount, the observer reporting "No" may become set to say "No" beyond the point on the physical scale which represents the least amount of light he can see half the time. Thus, for example, we can counteract this tendency by randomizing the stimuli. If we take several hundred such observations over a number of days we may, if we have taken every experimental precaution, now be in a position to answer the question; What is the least amount of light that can be perceived and located by the dark adapted observer half the time?

We plot the distribution of say log intensity or illuminance on X, and the frequency of positive judgments on Y. If the steps on X have been properly selected by the experimenter the stimulus limen or threshold will turn out to be a range, having a lower and an upper boundary, not a single point on the physical continuum. Then we can define the scotopic sensitivity of the observer in terms of the reciprocal of the means (or of the low and high limits) of the intensity which is just perceptible half of the time under the specified conditions of the experiment.

If you measure visual acuity at 6 meters with König bars, Landolt rings and Snellen letters you will get threshold ranges, partly determined by what the observer does and how he does it; partly determined by the methodology you use. It is not the least surprising that König bars will give for the same observer, a different threshold range than Snellen letters. This of course does not mean that one target is superior or inferior to another. It all depends on what your problem is; what you want to know about your observer. And, obviously, if you wanted to test the real comparative merits of Königs and Snellens then you must face another problem: Can you accept a statistical answer, obtained by taking the two measures on a thousand persons selected at random and computing the unreliability of the differences? Or would you prefer to take 250 measures on each of six trained and calibrated observers? The former is a normative experiment and assumes among other things that individuals will differ from one another, and that the positive and negative deviations will add algebraically to approximate the true means. The latter is an oppositive experiment designed to study the process and its determinants by the best precision techniques possible. The answer has to be given based upon fundamental knowledge of experimental psychology and mathematical statistics.

We deal with the stimulus limens or thresholds at both ends of the series of physical intensities. At the low end, as explained above, we determine the range of the RL (R standing for the German word REIZ which means stimulus) or stimulus limen. At the top end we may wish to determine the TR or terminal stimulus threshold. If you use an audiometer or oscillator you may want to find the "hearing loss" or lowest intensity of the lowest pitch frequency the ear can hear. Or you may want to determine the loudness threshold at the highest audible pitch. Here you may then get four thresholds, the lowest and highest pitch frequencies that can be heard at X decibels of sound pressure and the lowest intensity and highest tolerable intensity at these or at intermediate frequencies.

We deal not only with stimulus thresholds but also with DLs or difference thresholds. It is essential in building a psychological scale of intensities to establish an origin or zero point for our scale. This is taken as the lower RL. We now want to know how much must we increase the physical intensity above the threshold to discover the intensity which is just noticeably stronger, brighter, bigger or what not. This is one JND unit. From that point we want the one which is one JND above that, and so on until we have a set of equal JND steps to form our scale. As was pointed out in previous papers of this series the JND units are arithmetical increments assumed by definition to be equal because they represent equal perceptible increments. To produce them we find we must use a geometric series of stimulus increments. This is the fundamental notion of psychophysics; the more you have of anything, the more you have to add (or subtract) to make it just noticeably greater or lesser. The amount of intensity that must be added or subtracted is called the Weber fraction or Weber constant. It is written $\frac{\Delta I}{I}$, that is the ratio of a little bit added or subtracted from I divided by I, the base intensity, necessary to make it just perceptibly different.

Some of these Weber fractions have been determined with considerable accuracy, even though the fraction ~~is~~ constant usually only in the middle range of intensities.

For pitch of a tone of 2000 cycles per second $\frac{\Delta I}{I}$ was found to be 0.003 or 1/333; for visual brightness at 1000 photons, 0.016 or 1/62; for lifted weights at 300 grams, 0.019 or 1/53; tonal loudness at 1000 cycles per second at 100 decibels, 0.088 or 1/11; pressure on a spot on the skin at 5 grams per square millimeter, 0.136 or 1/7. Thus we may get some notion of the relative sensitivity of several important sense modalities.

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In science things and processes are defined in terms of operations. A scientific law states that when this happens, that will happen to such and so a degree. Thus a law is a statement of some relation. And this relationship is discovered by careful and precise measurement. From these measures one can state the law, which is usually expressed in some form of equation. So the basic concepts of psychophysics are fundamentally involved in all forms of human behavior. And it is a fair assumption that a very small percent of those who read these papers will have had, anywhere in their collegiate and professional training, even an elementary introduction to the experimental and statistical principles of psychophysics.

Historically, psychology as a science had its beginning about 125 years ago in the pioneering attempts of E. H. Weber, in Germany, to find the basic relation between the changes in the intensive physical continuum and the corresponding changes in the perceptual, experimental or psychological continuum. Up to this time the "mind-body" problem was one for rational and logical study, argument and debate.

When one sets about the measurement of stimulus or difference thresholds, the validity and reliability of the end result will, in very large measure, depend upon methodology. While a computing scale can tell the grocer how much to charge for six bananas at 5¢ per pound quickly and correctly enough, the determination of the amount of perfume a manufacturer can add or take away from a toilet soap before the house-wife can tell the difference is another matter. And when one considers the problems of measuring visual functions, such as acuity, phorias, stereopsis, space and form perception, size and distance relations, brightness and color, motion, flicker, etc., etc., there are two considerations which one must keep in mind. First, such "findings" are often taken as probe bodies or diagnostic signposts to show the trained operator the nature and extent of the imparment and what can and must be done to secure the optimal correction.

Second, the same functions or operations may be measured as research enterprises to discover means or norms and the amount of deviations which may be interpreted as serious enough to call for some type of prosthesis. This has been done by two investigators independently (Dr. Shepherd of Chicago and the writer) with essential agreement on analytical "tests" numbers 3, 8, 9, 10, 11, 13A, 13B, 15B, 16B, 17A, 17B and 19.

In our case the tests were made for me on 138 individuals by Drs. George Crow, J. Max Daniels, Mary Jane Skeffington and Charles Brooks. From their findings I computed means and standard deviations of the distributions. Let us take one example, "test" No. 3, the habitual phoria at distance taken by what is known as the modified Donders method. The mean for the 138 cases was 0.39 diopters exophoria. The range of +0.5 σ to -0.5 σ was 1.53 diopters exophoria to 0.76 diopters esophoria. The distribution of the whole range on this test is presented below to show what information one can get from any finding using this test and method.

Habitual Phoria at Distance.
(No. 3)

Standard Deviation	Probability of Occurence per 1000.	Diopters
3.0	1	6.49 eso.
2.5	6	5.34 "
2.0	23	4.20 "
1.5	67	3.05 "
1.0	159	1.90 "
0.5	309	0.76 "
Mean	500	0.38 exo.
-0.5	309	1.53 "
-1.0	159	2.68 "
-1.5	67	3.83 "
-2.0	23	4.97 "
-2.5	6	6.12 "
-3.0	1	7.26 "

This table can be read as follows. A person shows 5 diopters exophoria at far point on No. 3. This means he is 2 standard deviation units below the mean of the distribution, and 23 in 1000 cases or 2.3% per hundred can be expected to show this much exophoria at far. Thus one can say not only that this finding is low, but also how low. Of course such a measure is always interpreted not only in terms such as the above, but also is considered in relation to other types of test findings. This is a matter for the trained and experienced professional. It should be noted that these figures represent something that was done by somebody looking through an instrument containing prisms and reporting the appearance or alignment of a target under specified conditions of methodology. The words "habitual phoria at distance" thus mean an operation performed by a subject under certain defined conditions--nothing more.

Suppose we set up another kind of apparatus and method. Here the subject looks into an instrument containing base-out prisms at a stereoscopic scene. When he "fuses" he is asked to locate a white arrow seen at some point beneath a horizontal row of white dots, which at distance are 1 diopter apart. Suppose someone calls this a phoria, and since the results may differ from that of No. 3, begins a fruitless, pointless argument. Since the two operations are different and the conditions are different the only basis of similarity is the linguistic one of using the same name for them both. This is confusing and should not be done.

If we look again at the preceding table relative to the #3 measure of phoria at far it will be noted that a "normal" range of $+0.5\ \sigma$ goes from 1.53 diopters exo. to 0.76 diopters eso. The amateur looks at these figures and often treats them as points on a single continuum. Every "pro" in vision knows that the operations and relationships of other visual functions of the esophore differ materially from those of the exophore. So it is, to say the very least, highly questionable if not definitely impossible to regard both as the plus and minus regions of any single continuum. Since this is the case, such procedures as correlations, factor analyses and the like are almost certain to turn out as artifacts, if not conducive to positively wrong conclusions. It may be trite but still it is good advice to know clearly what one is about when working in this field.

Psychophysical metric methods are of two types. The first of these is one in which the stimuli are varied and the judgments are held constant. The most common of these is the Method of Limits, which is also called the J.N.D. Method, the Method of Least Perceptible Differences or the Method of Minimal Changes. Here one seeks to find the R (stimulus) or ΔR (difference stimulus) which yields a "sensation" S or ΔS which is just noticeable.

The procedure in the method of limits is as follows: The variable or comparison stimulus is first made equal to or very slightly larger than the standard S, then V is increased by small increments until the subject reports it just perceptibly greater than the standard. V then is increased still more and from this point gradually diminished until it just ceases to appear greater than S. The the procedure is reversed and a starting point is selected less than S and a series made to determine the point which is just perceptibly less than S. These are sometimes called the Method of Complete Ascents and Descents. Thus one may determine the upper and lower threshold limits of the DL or difference threshold.

The most common errors in this method are of two types: (1) time errors and (2) space errors. These two are classes as Constant Errors, because they are usually in the same direction. Then there are Variable errors, due to set or attitude, practice, habit and fatigue. And finally Accidental errors due usually to unknown causes. A good investigator plans his procedure so as to minimize or eliminate all error possible.

The second method is called Average Error, or the Production Method. Here the subject is asked to adjust a variable stimulus so that it seems to him subjectively equal to a standard stimulus. In a typical experiment in lifting weights suppose we have a standard brass cylinder whose weight is 40 grams. We also have an empty cylinder and a vessel of no. 6 lead shot. The subject adds shot until he makes V equal subjectively to S. Then he starts with his V cylinder full and so definitely heavier than S. Each time the experimenter weighs the V accurately. Fifty to 100 judgments are made each way. Standards may be, say, 20, 40, 80, 160 and 320 grams. The results are finally computed as means, standard deviations, etc. The difference between the mean and the standard is called the crude Constant Error and it may be either positive or negative, of course. It is an error whose conditions are constant; its amount may vary quite considerably from stage to stage in a long series of experiments. Generally speaking the scatter of the individual's scale points or errors obtained by the method of limits will have little relation to that obtained by the average error or production method. Although they are not entirely unrelated, it is clear that the operations of the subject are not the same, and it remains for the investigator to know and use which method is best suited to find what he really wants to know.

Next time we will consider the second group of methods, in which the judgments vary and the stimuli are held constant.

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PERCEPTION LVIV

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Before continuing our discussion of the metric methods for intensity measurement, there is another widely used method belonging to the first group of methods (those in which the stimuli are varied and judgments are held constant). This is a method called Equal Sense Distances or Equal Appearing Intervals.

The method of equal appearing intervals is essentially, first, a method for establishing a scale. Suppose for example I wish to make a scale for measuring the legibility of handwriting, say of adults. I ask 300 adults to copy the first three sentences of Lincoln's Gettysburg address. With the 300 samples from an unselected group of all kinds of people my job now is to select from all these samples representative specimens to make up a scale which will have at one end the most perfectly readable writing I can find and at the other end of the scale a representative sample of the most illegible writing in the lot. Then I have to decide how course or fine a scaling we want. I may want only a good-poor scale; so I select a sample which is average--neither the best or the poorest but which ranks half way between the extremes. Then I can look at each sample and put it in one or the other of the two classes or groups--good or poor. But this isn't much of a measuring scale.

I can bisect the interval by finding a sample which a group of competent judges agree rates midway between the lowest sample and the mean; another midway between the mean and the top. Then we have a scale of 4 classes or intervals. In a 5 step scale, such as college marks, A is superior and about 7% of a large sample of students in a course will earn this mark. B is good, and about 23% will get this mark. C is average and about 38% will get the mediocre mark--not bad--not good. D is poor and 23% will rate D. E or failure will be received by about the bottom 7%. This totals 98% because we are not too concerned with fractions and follows the general mathematical probability curve. This is the function used to compute the betting odds in a game played with small ivory cubes in which one sometimes hears the words "snake-eyes" and "box-cars." Seven comes up oftener than any other number between 2 and 12, simply because there are more combinations which add to 7 than any other number between 2 and 12, assuming of course that each die is true.

I may want a 10 step scale or decile scale to measure handwriting legibility. If so I may get a large group of bankers, writing teachers, etc. to judge the samples, sorting them into ten piles. Then by some rather laborious statistics I can determine a specimen of writing which belongs in the middle of each scale division. Once the scale is made, then each new sample is compared to the scale and its value established when an interval is found which has equal legibility to that scale division.

There is, of course, a number of such scaling methods, almost all of which involve the assumption that the mean or consensus of a large enough group of competent judges will approximate the true value and the trustworthiness of this mean will depend largely upon its own root mean square error or standard deviation. In 1910 Thorndike of Columbia University had 40 judges sort about a thousand samples of penmanship in eleven equally spaced groups or intervals. In order to be free from the end-effect errors he added samples at both ends better and poorer than any to be scaled. This scale has been extensively used in education. As examples of other scales, Professor Hollingworth scaled some 30 odd jokes and Professor Hillegas used the method in setting up a scale for measuring English Compositions.

Critics of the method of equal appearing intervals have shown that it does not agree too closely with the more rigorous Constant Process or Paired Comparison Method (to be described later); that intervals at the high end tend to be underestimated as compared with those at the low end. So again, the choice and proper use of any method remains a matter for the trained worker--trained in experimental psychology and mathematics. (A good book on the whole subject is J.P. Guilford's 2nd edition of Psychometric Methods published by McGraw-Hill, N. Y., 1954.)

There is another way one can measure legibility, this time experimentally, I can place the samples in a focal variator, an instrument designed by my teacher and good friend, the late Professor A. P. Weiss. This has a lens system so arranged that the sample can be varied from complete blur to maximum clearness and sharpness with image size and brightness held constant. Legibility then can be measured in terms of how far out of the blur toward clear do you have to bring the sample to be able to read it without effort.

The late Professor Thurstone experimented extensively with the method of equal appearing intervals using 96 cards on which random black dots were printed. The lowest number of dots was 68 and the highest 198. By building a scale of equal intervals one can determine the number of dots which are added to make the next scale point an equal distance above the last one, and the accuracy of the judge determined in terms of the standard deviation of his judgments at each point. Equal phenomenal or perceptual intervals arithmetically are produced by a geometric series of increments of the number of dots which must be added to make the next scale step as much denser than the last one is over the one immediately preceding it.

The second group of metric methods reverse the procedure of the first group. Here we keep the stimuli constant and vary the judgments. A single example will suffice to make this clear. As a sample let us consider the Constant Process Method. By many this is considered the most accurate and precise of the psychometric methods. This is because it permits the better control and virtual elimination therefore, of space, time and systematic errors. Historically the method was developed in 1888 by Joseph Jastrow who named it the method of right and wrong cases.

It may be used for determining absolute thresholds, difference thresholds, equal appearing intervals and other measures that are of psychophysical importance. Let us note an example of how this method operates. Suppose I set up a series of brass cylinders weighing in grams:

32 34 36 38 40 42 44 46 48

with 40 grams selected as the standard. How many grams do I need to increase or decrease the 40 to find the least perceptible difference from the standard?

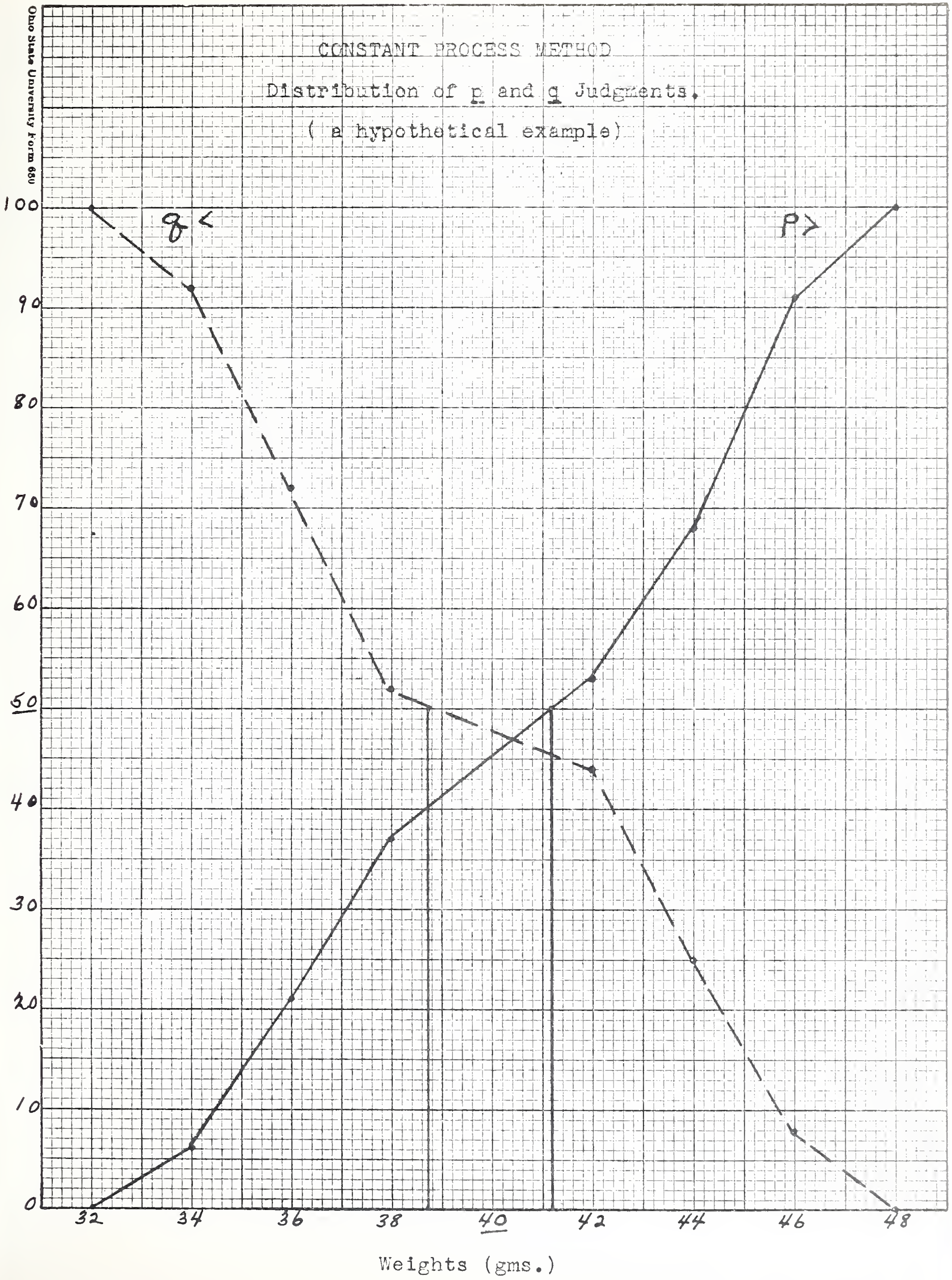
I present two weights in a cubic screen so that the observer lifts but does not see the cylinders. He is instructed to judge yes or no whether the second is heavier than the first of two weights, lifted not more than 3 seconds apart in time and varied in order randomly as to S or V variable being presented first or second, I start with say 34 and 40 and the observer judges these 50 to 100 times. I then have a frequency in percent of P> (positive-greater-than judgments).

I present next say a 46 and 40 and find out the value P for 46 grams. I do this for each V weight. Then I repeat the experiment, this time calling for q judgments. Here the instruction is "Tell me yes or no whether the second weight is lighter than the first." I take, say 100 judgments at each V compared to the standard S. Finally I have a table of results which may look something like this!

Weights in Grams

					S				
V	32	34	36	38	40	42	44	46	48
p>	0	.06	.21	.37	--	.53	.68	.91	1.00
q<	100.	.92	.72	.52	--	.44	.25	.08	0

Plotted these figures look like this:



CONSTANT PROCESS METHOD

Distribution of p and q Judgments.

(a hypothetical example)

It will be noted that in our hypothetical case the points at which the 50% abscissa cuts the two curves bound the indifference zone, that is the upper and lower thresholds about the standard of 40 grams. That is to say any two weights falling in the range of 38.8 and 41.2 grams are equally likely to be called heavier or lighter than 40. The standard 40 is thus psychologically a range and not a point. This is done by plotting and is therefore not as accurate as we may desire.

We can, in the simplest case, compute the probable lower DL, a difference threshold, by simple arithmetic interpolation. For example the obtained value of $p >$ at 38 grams is 0.37. Our problem is: we get 37% of judgments on 38 grams reported heavier than the 40 gram standard. What weight would we have to have to raise the percentage to just 50? We need 0.13 of the 2 gram interval to be added to 38 grams. Hence at 38.26 grams, by interpolation, we have the lower limit of weight judged equal half of the time to 40 grams. The upper limit likewise, by arithmetic interpolation, will be at a point less than 42 grams since there are 53% of judgments positive or heavier at 42 grams. So .03 x 2 - 42 = 41.94 grams.

For the *q* judgments the range is 37.96 grams below and 41.88 grams above the 40 gram standard or a range of 3.92 grams, which is slightly larger than the 3.68 range when the judgments are *heavier*. Thus while $p + q = 1$ mathematically it is *not* true that $p = 1 - q$. And there is no real reason why we should expect it to be so.

Thus by arithmetic interpolation anything from 38.26 grams to 41.94 grams is equal perceptually to 40 grams, and the range of the zone of indifference is 3.68 grams.

One defect in simple interpolation is that we only use two values to compute the upper and lower limits of the threshold range. In some cases it is necessary to determine the limits with the utmost precision. Here we must compute the contribution of each experimental point to the shape of the whole curve and the exact point at which 50% would fall if we knew exactly what weight in grams to compare to the standard. Here we resort to the calculus and use Lagrange's method, a description of which takes us far beyond the limits of these papers. If interested you can read how to do it in Whittaker and Robinson's *A Short Course in Interpolation*, Van Nostrand, N. Y., 1923, pp. 28-30.

This is enough for now. Next we will consider two addition methods: Paired Comparisons and Rank Orders and then we will be in position to talk more about such things as information or input theory and where it fits into the general understanding of the theory and problems of perception as we encounter them in a practical way.

I should like to close this paper with a quotation from a book by John Tyndall on "Lectures on Light." "Behind all your practical applications, there is a region of intellectual action to which practical men have rarely contributed, but from which they draw all their supplies. Cut them off from this region, and they become eventually helpless."

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PSYCHOLOGICAL OPTICS

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PERCEPTION LX

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The fundamental pattern of any judgment is that of paired comparison. When something is shown to us and we are asked a question like, "Is this a high or a low pitched tone? Is this girl's face beautiful? Is this apple pie good"?, we compare the submitted sample with some kind of a standard of reference. This may be implicit, that is it may be carried as an organized memory trace system, a "concept", a notion of what one is able and willing to accept or reject as meeting our "standard." This standard is a dynamic set of processes and so it is not surprising that it may and does change with prevailing conditions. A man who would not shove you aside in a line to buy a ticket, may, behind the wheel of his powerful car, become a ruffian and a boor. Some people have one set of such standards out "in society," another "at home," and still another in business or professional life.

In the psychophysical method of Paired Comparisons we have as our problem the answering of a question like this: Here are 16 Hering Colored papers each 2 inches square. I want to know the preference order for these 16 colors. Which is the most preferred, and so on to the least preferred.

Do not be troubled about the meaning of preferred. Just follow instructions. I seat you in front of a medium gray screen 22 x 28 inches. Side by side in the middle of this screen are two 2 1/2 inch square holes. Back of the screen are two large disks on the front of each of which is fixed at the rim 16 Hering hues. A shutter opens the two apertures and you see two patches of color side by side. I ask you to look at them and tell me: which do you like better, the right or left one? You must chose one or the other.

I then show each one paired with every other one. The number of combinations C of 16 things taken two at a time is given by $C = \frac{n(n-1)}{2}$. Where n is 16 this becomes $C = \frac{16 \times 15}{2} = 120$. It is conceivable to arrange them in a table, like the one shown on page Number 29.

The table shows the order in which the comparisons are made. I compare 2 with 1, 1 with 3, 4 with 2, 3 with 4, and so on. I finally have the frequency of preference for each color compared with every other color in the series. I can repeat the series as often as I wish to increase the reliabilities of the frequencies of preferences. One can then plot the preference values and tell how much each hue ranks above or below its nearest competitor.

For the "full treatment" we may also wish to know the distribution of the negative preferences. Here we run the same series of judgments, now asking "which of the two is less preferred"? We plot these and find that dislikes are not the opposite of likes. Some hues change places, so that likes are not really the converse of dislikes.

Last year a large corporation gave us a contract. They make and sell, among other things, flashlight batteries. Their artists and designers sent us 4 counter displays all the same shape but differing in color. They wanted to know which one will attract more people and how does their best display compare to those of their two leading competitors. We ran the experiments and found the answers and they were well pleased. One could do the same for example with shapes and colors, etc. of spectacle frames. Guilford presented a table showing by this method the ratings by 100 male college students of twelve well known male movie actors. Another study presented preferences for 9 kinds of vegetables. If you are interested, corn was first, followed by peas; close to which was string beans. Then about midway came spinach, carrots and asparagus, followed lower in the scale by beets and cabbage, and very low at the bottom of the list was turnips, as judged by some 237 males. Do you agree or disagree?

Finally we need to consider the Method of Ranks. In the simple case we may proceed as follows. I have 10 pictures made of western mountain scenes. These are all 11 x 14 prints on white 16 x 20 mounts. Each bears a code letter for identification. Each observer is instructed to examine the 10 pictures and select the one he believes he could live with; the one he regards as the nicest, most beautiful, most attractive picture. He ranks this No. 1. Then he may select the poorest one, which he ranks 10. Then he selects the second best and so on until he has his rankings for each of the 10. He may do this several times and on different days. If we have 35 people make rankings we can then statistically find the mean rank for each picture and its standard deviation. Now we are in a position to scale the pictures. In fact we are in a position to do a number of interesting things. So far we have only a mean ordinal scale--first, second, third, etc. But sometimes it is desirable to transform these mean ranks into centile positions on a normal probability curve of distribution.

This may be done as follows: To find the centile position, that is where it stands on a scale of a hundred steps between $\pm$ 3 standard deviation units below and above the mean, we first transform the mean ranks secured above into rank values. Rank values are the inverses of the primary ranks. Let this be designated at R_i. This merely gives low numbers to the high ranking pictures and high numbers or values to the low ranking ones. Then we can find the mean rank values, the centile positions of which are given by

$$CP = \frac{(R_i - 0.5)\ 100}{n}$$

where CP means centile position, R_i is rank value and n is the number of ranks.

If r_i is the original rank made by the observer then R_i is related to r_i by the simple equation $R_i = n - r_i + 1$, or this may be written $R_i + r_i = n + 1$. Each centile position thus falls in the middle of one of the 9 ranked areas.

Actually the ten pictures show that the preference distances between the pictures, as ranked by my laboratory students, are smaller in the region of the center and become larger at the top and bottom extremes.

But when we make a scatter plot comparing relative positions when the 10 pictures are scaled by Paired Comparisons and plotted against the scaling by Ranks, the correlation was high, being about + .90. So we may decide that Ranks, which are much less laborious and time consuming, will give us just about as good results as the other procedure.

In cases where we wish to determine the trust trustworthiness of our obtained differences between the displays of our battery manufacturer and those of his competitors we may apply what is known as the sign test statistically. This formula is given as:

$$Z = \frac{2\ (P_o - n/2)}{\sqrt{n}}$$

Here Z is the measure of trustworthiness of a difference of two distributions with no assumption as to the normality of distribution; P_o = all plus cases (i.e., all ranks above the mean) + one-half the zeros; n = the number of pairs of ranks.

This is one of several non-parametric procedures for treating such data and was described by Brandt, in the J. Amer. Stat. Assn., 1933, 38, 434-437.

Where the value exceeds 1.96 for Z, any observed difference can confidently be taken as a true difference and not due to chance or the fluctuations of sampling, etc.

Z values for the four battery displays and the two competitive displays came out at 2.35; 4.70; 3.13; 4.31; 3.52; and 4.70.

So statistically we are safe in drawing

conclusions as to the relative preference values. It will be of interest to see later how market research on sales agrees. Usually this has been found to check closely with the laboratory findings.

Why bother with all this discussion of intensity or psychophysical methods? Well, for one thing, you in optometry have to work with it every day, whether you like it or not and whether you do a good or indifferent job, often with observers not very consistent or capable of making judgments of small differences or likenesses. Then too there is the broader question of the roles played by the stimulus and that by the perceiver.

As soon as the first transformations are made by the sense organ then the brain, effectors and feedbacks take over and organize, form and structure the input energies into that which perpetually is antecedent and prodromal to behavior. With greater training and ability the role and importance of the stimulus as a determinant becomes less and less and that of the organism greater and greater. Knowing how to measure and control the stimuli and to train the operator to handle them better and better is a most important enterprise.

Table Showing the Order of the Comparisons

	R 1	YR 2	YR2 3	RY 4	Y 5	GY 6	YG 7	YG2 8	G 9	BG 10	BG2 11	GB 12	B 13	RB 14	BR 15	BR2 16
2	1															
3	2	3														
4	30	4	5													
5	31	32	6	7												
6	55	33	34	8	9											
7	56	57	35	36	10	11										
8	76	58	59	37	38	12	13									
9	77	78	60	61	39	40	14	15								
10	93	79	80	62	63	41	42	16	17							
11	94	95	81	82	64	65	43	44	18	19						
12	106	96	97	83	84	66	67	45	46	20	21					
13	107	108	98	99	85	86	68	69	47	48	22	23				
14	115	109	110	100	101	87	88	70	71	49	50	24	25			
15	116	117	111	112	102	103	89	90	72	73	51	52	26	27		
16	120	118	119	113	114	104	105	91	92	74	75	53	54	28	29	

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PERCEPTION LXI

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Before proceeding further into the problems arising from the operations involved in intensity discrimination we need to mention a few things.

If we ask what the mechanism of intensity discrimination really is, we are compelled to answer that we do not know, although at the same time we can truthfully state that we do have a number of facts that throw some light on the problem.

Our sense receptor organs are compensatory devices. If, for example, a loud tone is delivered to your ears, the tensor tympanic muscles which control the tension of the ear drums relax; if the tone is weak, they tighten up the drums. Likewise behaves the stapedius, which controls the chain of ossicles, the hammer, the anvil and the stirrup. So the pressure transmitted to the liquid in the cochlear tube tends to be kept somewhere near a mean value. How then can we make such fine discriminations of small differences of pressure and therefore of loudness?

Any nerve cell, whether in Corti's organ in the ear, or a rod or cone in a retina, operates on the all-or-nothing principle. If the stimulus is above threshold the cell responds maximally in all its parts or not at all. But any stimulus excites hundreds and thousands of cells. If we assume that higher sound pressures or brighter illuminance activates more cells, proportional to the physical intensity of the stimulus, then we must assume that the spread of excitation in the brain will be greater and the ensuing effector processes in muscles and glands will be stronger. The feedback from the effectors then becomes the information carrier of the intensity level of the stimulus. This of course assumes a constancy of relation between response and stimulus which obviously does not exist.

But, here, all is not sweetness and light. If I select a spot on the skin of my volar forearm and double the area of the spot stimulated, at the same pressures, I do not feel greater pressure, only larger area. If I double the area of a light spot on the retinas, I do not get a discrimination of double the brightness. If I vary the time of the exposure I may demonstrate the Roscoe-Bunsen law, that

$$I \cdot t = C$$

that is, intensity times time is a constant. So if I use a higher illumination level but reduce exposure time, I can produce the same discriminal effect as if I used a lower intensity but for a longer exposure time. If now I vary the area of the light spot and work in the central region of the retina I may show that

$$AI = C$$

This is Ricco's law. Area times intensity is a constant. And if now I move off axis into the periphery, following Wald's work, which assumes that any threshold response must involve a constant number of retinal elements stimulated, I find that

$$(A - Nt)^k I = C$$

where Nt is the number of elements stimulated. If now the exponent K is 0.5 then Ricco's law becomes Piper's law, which states that $I \sqrt{A} = C$, and this has been found to hold for the periphery within the range of 2 to 7 degrees. Stated simply, Intensity times the square root of the area is a constant in the periphery.

Compairing this with Ricco's law it is evident that with the greater rod population in the periphery the role of the number of elements firing must be a determinant of discriminal brightness. Why then should not increases in the number of quanta of energy produced by stimulation increments proceed regularly, continuously and progressively? That they do not is well known. Increments (discriminal) go step-wise.

One way out, proposed by Wever and Bray, was that increased intensity of stimulation produced increases in the number, wave length and amplitude of the afferent volleys. Such matters as cross section diameter, medullation, surrounding electrolyte and length of the fibril give differing patterns of sine waves, and these, in this theory, become the paradigms of signal intensity.

The volley theory is backed by these facts, but it is also faced with serious problems. The eyes can make millions of color and brightness discriminations. One difficulty is to figure out how to get enough volley patterns to correspond to the number of discriminations. Another is the objection that the input signal is thus assumed to carry the entire determination of any quality-intensity relation. The brain, the chemical conductors and the effectors, what roles do they play?

Well, no matter what we choose as our theory of intensity, there are certain facts which cannot be denied or disregarded. Input signals reach diffused regions of the brain which are already active. Sets and instructions, kinetic and prodromal activities such as postures, residual memory trace systems, all form a matrix which in addition to the input signal determine such things as compatability, availability and eventually the kind of movements and actions that will ensue, and finally there are the pace-setting and maintaining effects furnished by the backstroke. From these, it is a fair presumption, come the meanings of louder, brighter, etc.

No matter how we elect to regard the mechanism of intensity, the fact of adaptation-level is well known and well established. If you have driven to California through Nebraska, Wyoming, Utah and Nevada, going at 60 or 70 miles per hour, then you come to a town with a 25 mile limit, and prowl cars and timers and radar checks to see that you do it, no one has to further convince you of the meaning of a perceptual speed scale shift or change in adaptation level. Perhaps we should say that whether familiarity breeds contempt or increased caution or better understanding and sureness depends thus upon the subsequent consequences to the organism--the furthering of its goal seeking activities--of the whole train of events, before stimulation, as well as through the entire course of the instigated processes. The "schemata" which Bartlett described as the organized residuals from prior experience must be the things which enable the Australian tracker to see and hear much more than is furnished by the stimulus input. It must be the "savoir faire" which enables the cardiologist to hear heart sound that I can't hear in the same stethoscope, even though my hearing loss is distinctly less than his. Tolman called attention years ago to what he called "the recession of the stimulus." With increased age, experience and training we need less intensity, duration, area, etc., of the "stimulus." The perceiver can respond to weaker and weaker signals, so I propose that a parameter of the perceiver's contribution has simply got to be written into any law of intensity discrimination just as it must be a factor in the perceiving of form, size, position, motion, etc.

It is quite likely true that, in spite of the imposing body of facts gained by the neurophysiologists, the psychological problems of intensity discrimination are still very much with us and are far from being settled. We can determine, with quite high accuracy, stimulus and difference thresholds. We may, with hope and confidence, expect that at some future time the puzzle of intensity will find solution. But it is not available today.

As we look about at the problem now and then a new and approach puts in appearance. Reference was made to one of these a few papers previously--what has come to be known as information theory. We need to know more about it since so many have had so much to say and do about it. Our next paper will attempt to introduce you to it and to consider its bearing on the topics of this series.

VOLUME 29 — OPTOMETRIC EXTENSION PROGRAM PAPERS — (POSTGRADUATE)

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PSYCHOLOGICAL OPTICS

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PERCEPTION: LVVII

July - 1957

Series 17 No. 10

In the immediately preceding papers we have had a quick look at the problems and methods involved in the measurement of intensity, or psychophysics. This is really where, historically, experimental and theoretical psychology got its start. In the earliest days the question was that of finding a law of the relation of physical stimulus increments to perceptual steps of "just perceptibly greater than" or "just less than" when the stimulus was progressively increased or decreased.

The problem, in these times past, of psychology, was to measure the stimulus energy or intensity, and from this to predict the nature and magnitude of the response. This, of course, threw the whole matter into the lap of mathematics, particularly the mathematics of probability. If one could assume, as many did, that the functions being investigated operated like rolling a pair of dice then it became a relatively simple matter of showing that upon the presentation of any stimulus of specified intensity, the probability of any specified response could be deduced from the Gaussian or "normal," i.e., pure chance, distribution.

But it soon became apparent - (By "soon" here we mean about a century!) - As Professor Boring once aptly put it, nature does not abhor skew distributions. In fact, very few if any psychological functions operated like dice, that is, gave a nice regular "normal" bell-shaped Gaussian distribution. Some did, many did not. So, thanks be, a few brave souls began to doubt that the nice, precise, "rigorous" law of the relation of stimulus intensity to response would hold, except within a very limited range, and this it did.

The doubters questioned the stimulus as the really important vehicle of meaning or of response and said, in essence, let us look elsewhere. A critical look at stimulus found it difficult or impossible to define--i.e., to set its limits, especially in time.

As I have shown previously, as early as 1896 Dewey was unhappy with the stimulus-response doctrine. He pointed out, for example, that "the stimulus" always lies inside and not outside the act. To be stimulated one has first to make a response of some sort or other. The eyes, for example, have to focus and change relative positions before the entering ray sheaf can form minimal blur circles in the region of the foveas. Movements, actions thus began to take over the position of primacy hitherto ascribed to stimulation.

Then, too, a half century ago it became apparent that the sensory functions were not independent and autonomous. Experiments by psychologists at that time, working under as rigorous conditions of control as they could contrive, could not succeed in making the perceptual synthesis, wetness on your forehead, for instance, was merely a combination of sensations of areal pressure, temperature, etc. But efforts to add together the sensory components to produce the end result failed--something was missing.

It became evident that seeing, hearing, tasting, etc. was done by a whole organism and that no matter how precisely the input signals (stimuli) were specified and measured, probability prediction was not very good because, as Titchener once put it, "one always perceives more than is furnished by the stimuli." That is, one always refers or relates the input signals to residual frames of reference, and these turned out to be mainly the backstroke inputs from the effectors reporting the nature and extent and consequences of the responses instigated by the stimuli.

So instead of reflex arcs people began to think and talk about organic circuits, homeodetic circuits-the closed loop circuits of the electrical engineers in the modern day.

What I am driving at is simply this: A systematic position or theory in science is usually achieved by a long, slow process of growth or evolution. It is often the contribution of many scholars; of much of what Mr. Churchill called "blood, sweat and tears," in most cases mostly sweat. But truth seems to have a way of arriving. It is sometimes distressingly slow and painful. We often wonder why in blazes someone wasn't smart enough to see some simple but powerful truth. Look, for example, at the history of mathematics. It took centuries to discover the short cut and labor saving convenience of logarithms; and many, many more years to extend this to decimals and to see the positive gains for us by postulating imaginary numbers (of great practical value) such as $\sqrt{-1}$.

For example if I set down the series of numbers:

1 2 3 4 5 6 7 8 - log series.

2^1 2^2 2^3 2^4 2^5 2^6 2^7 2^8 - exponential series.

2 4 8 16 32 64 128 256 - antilog series.

This is the series as Archimedes saw it. Then Napier came along and he said, "Let us call the top series a logarithmic series and the bottom series antilogarithms. Archimedes principle was simple that if we want to multiply any two numbers in the bottom series, we add up the corresponding numbers in the middle series and look for the number in the bottom series. So, suppose I wanted to know, How many are 8 times 16? I merely need to look at the generalized formula:

$$a^m + a^n = a^{m+n}$$

So $$2^3 + 2^4 = 2^7 = 128.$$

If we add the exponents of the numbers, the product of the two numbers will be the antilog of the sum of the exponents to the base 2, or 8 x 16 = 128. So here was a real laborsaving device.

In like manner it was seen that since:

$$a^0 = 1,$$

$$\text{then } a^{-1} = \frac{a^0}{a^1} = \frac{1}{a}$$

$$\text{and then } a^{-2} = \frac{1}{2} \div a = \frac{1}{a^2}.$$

So one could generalize that $a^{-n} = \dfrac{1}{a^n}$

So that Archimedes rule holds also when m and n are fractions in the equation:

$$a^m \times a^n = a^{m+n}$$

Then if the exponent was a fraction, like a 2/3, it was shown (about 1350 AD.) That:

$$a = \sqrt[3]{a^2}$$

My point here is merely that it took human scholars a thousand years to learn, or to see, that the simple rule of Archimedes could also apply to a fractional or to a negative power.

From Archimedes to Briggs and Napier bridged the years from about 250 B.C. to 1631. This is how long it took to see in the (to us) simple exhibit of the three series of numbers, the log, the exponential and the antilog, just how they are related and, more importantly what marvelous things the person can do with them who has learned even a little of the fine art of mathematics.

In our counting and computing activities we are trained to use the 10 base or decimal system, for example in our money system. How effortful it is for us to think and transact business in shillings, pence and pounds sterling. And our British cousins are probably often wondering at our methods.

It has taken us about 300 years or more to gain an appreciation of many, but by no means all, of the things we can do with logarithms to the base 2, rather than to the base 10. And, when we must deal with time series, such as rates of growth, computing compound interest, etc., the number Epsilon (ε) which is

$$1 + \frac{1}{1} + \frac{1}{1x2} + \frac{1}{1x2x3} + ---- \frac{1}{!\ n},$$

or $\varepsilon = 2.7182818$, is really a major achievement of the human intellect.

The English mathematician, G. Boole, wrote a paper on the mechanism of thinking in which he showed that when one must make a simple binary decision: yes or no; stop or go; turn right or left; etc., one is then able to assemble the frequencies of such decisions into groups or classes. From such data one may be interested in making predictions based on probabilities. This is a case where our friend $\log_2$ comes strongly into the picture. And, hardly anyone paid any attention to Boolian algebra really for some seventy-five years after its publication, but today the electrical engineer would be "hard-put" to design the circuits for a television set or an electronic computer without this powerful tool.

In the Newtonian physics if anything happens now, it happened as the resultant of all the things which happened before. The past ruled the present. This some Frenchman called le morte main principle--the dead hand--which still is far from dead.

But physicists soon saw that predictions from past information gave low probabilities in dealing with certain phenomena. In sub-atomic physics, ultra high frequencies or very low temperatures, the principles of the quantum mechanics of Heisenberg, Einstein, etc., showed that sets or fields of forces demanded a broader form of treatment than that of the classical Newtonian physics.

In biology likewise the conditioned reflexes of Pavlov and Bechterev were too easy a way out. The organism was coming to be seen as a vast system of networks and feedback, positive and negative, controls and that the human being's behavior with its unique use of symbols and its understanding made possible often times solutions to problems and so reduction of stress states in ways that were new and unpredictable from anything which could be gotten from the behavior history of the organism previous to the now.

Scientists, i.e., mathematicians, physicists, electrical engineers, biologists, chemists, psychologists and also social scientists, began to see that some things --many things--worked much the same in all of these fields. Could it be that progress heads in the direction of unity and simplicity as understanding becomes great enough?

One of these many-sided developments has been the development of communication or information theory. Next time we shall try to show what it is and how it applies to the problems of our interests.

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It may not be immediately apparent but there is a plot, design, schema or plan in the order of these papers. We have taken up several of them in reviewing the history of the problems of intensity discrimination and the measurement and scaling of these processes. Not only was it shown that with the advent of psychophysics, experimental and theoretical psychology became a division of science. But also an attempt was made to show that in the perceiving of small differences we are dealing with one of the most modern and most important problems within the realm of our interest.

A long time ago a German scholar asserted that the difference between man and the other vertebrate animals could be stated thus: Man talks, laughs and cries, and makes love at all seasons of the year. If I may presume, I should like to add that man not only talks, but now and then says something. And this fact that he may communicate in symbolic form with others, not only with articulate sounds but in writing, with blueprints, photographs, television, radar, etc., means that he has multiplied the range and importance of his activities because by such means he can figuratively if not literally hook up his sense organs to the effector systems of others at a distance. So his world of space-time takes on new dimensions.

In his development of his brain, sense organs and effectors, man has invented more than 2000 languages. From the earliest time it must have been clear to him that talking to himself, subvocal talking, was not only a private matter, but that it was closely related to his basic understanding of things and processes and was perhaps the chief mechanism in problem solution. If he shot an arrow and missed he could shoot another and correct his aim. Primitive man remained primitive for centuries because he could not understand and control the organization of the after-effects of the feedbacks from his muscles and glands.

In winter the temperature of this room is controlled by a thermostat which I may set at my option. Its function is to maintain an approximate homeostasis, so that the rate of heat loss of my body stays within some tolerable limit. If the furnace is on and not until the rugs and furniture smoke does the thermostat turn off the the gas, then the thermostat is of no use to me simply because it is not discriminating enough. And conversely, if it kicks on and off with changes of room air temperature of a hundredth of a degree, then perhaps the furnace develops a neurosis wondering what in blazes goes on up stairs that whoever or whatever it is can't decide when they are too warm or too cold. Basic and fundamental to all communication theory and practice is thus the fundamental psychological fact of the importance of how much do you have to change something to make it just perceptably different.

So communication or information theory broadened out when the mathematicians, physicists and electrical engineers set about to build an explosive device which would be steered to its target by the target itself and "know" when to detonate. And we should be eternally grateful to the relatively small number of men who have developed these top secret devices for the maintenance of freedom and safety. Names like Von Neumann, Wiener, Turing come to mind in this connection.

One of the real pioneers in the development of communication or information theory was a mathematician and engineer for the Bell Laboratories - Claude Shannon. Shannon wanted to know how much "information" could be carried by any conducting communicative system before overcrowding and jamming occured, and how such systems could be extended by the use of shorter and more efficient coded signals. This the engineers call channel capacity.

Since it is impossible here to give more than a barest sketch, Shannon's papers "A Mathematical Theory of Communication" are to be found in Bell Syst. Tech. Jour., 1948, 27, 379-423, and 623-656.

Information as used here is defined in terms of the degree of uncertainty at the receiver end of a message, which consists of a series of choices among alternatives. Information thus is a signal and has no intrinsic meaning. The uncertainty or certainty as to what message the receiver will get involves the mathematical theorem of probability. Certainty is equated to the likelihood of the receiver guessing the message before it is transmitted. The guesses must therefore be governed by some probability distribution.

Shannon developed the fundamental formula for the uncertainty of the receiver (H) showing that $H = -\sum p \log p$, where p is the probability of each alternative occuring in the population of messages at the transmitter. The receiver at the other end of the communication channel does not know what message he will receive. Shannon was interested in predicting the probability of the receiver "guessing" the right message.

The amount of information that can be carried per unit item of the input signal, word, symbol, etc., he said, is the logarithm to the base 2 of the number of possible judgments, choices or responses. In the simple case if the message calls for a decision "Is it now afternoon"? the answer can be yes or no; on or off; open or closed; stop or go; plus or minus, etc. So that whenever there are two and only two possible responses, the "information" carried by a binary digit (say for example 1 for yes and 0 for no) is $\text{Log}_2 2$ and this equals one bit of information. Bit is a coined word derived from the first two letters of binary and the last two of digit. Thus one bit is one quantum of information.

The amount of unavailable energy in a system is its entropy. So we may call the H in Shannon's equation the negative entropy of a system. Thus H is a measure of the degree of organization, structuring, degree of design, amount of significant detail, or the appurtenace of subregions existing within the system at any particular moment in time. Here we may see the close tie between this information approach and the problems we have been interested in which deal with perception. The retina transforms light input signals into the coded afferent impulses within the nerve network. These weak energy, relatively slow moving, virtually transmitted signals are received by an elaborate nerve net system, the brain, which as Stroud and others have shown, enables us to be conscious about ten times per second, but like other similar phenomena such as visual apparent movement, we experience not as an intermittency but as a unified and continuous thing.

If we suppose that the coding, re-coding and decoding may have various degrees of negative entropy, as must surely be the case, then coding systems may vary widely. If such a system is as long and complex as the original message (or even longer) then coding is a waste of time and energy. The extent to which language or any message can be compressed by coding if the best possible code is used is designated as redundancy.

Using tables of the frequency of words in English, Shannon calculated the amount of redundancy due to the unequal probabilities of the words. He found this to be 54%. So one can take considerable comfort in the fact that our understanding vocabularies are much larger than our speaking and writing vocabularies, and at the same time go to work in our speech and writing to emulate the splendor of the language of the Gettysburg address, of Shakespeare or of the Bible. Lawyers and law makers might do well to ponder some of the implications of information theory.

The alphabet contains 26 letters. So each letter can have $\log_2$ of 26 which is 4.7 bits of information. But letters are combined into words, phrases, sentences, paragraphs, sections, chapters, arguments. To the extent that we are trained, from these larger groupings or unities, we read meanings which can vary widely from blur to clear.

Miller, of Harvard, has pointed out that here is one of the important issues in information or communication theory. This thing of grouping, the thing which I have argued on the basis of many years of experimental evidence, is the primary function of short-exposure or tachistoscopic training, is the base upon which information theory must stand or fall in the probability of its answering the fundamental questions of how we perceive form, space, time, motion, etc. But more about this next time.

If you are irked at the redundancy of my scribbling, I beg you to "fo' give muh".

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19

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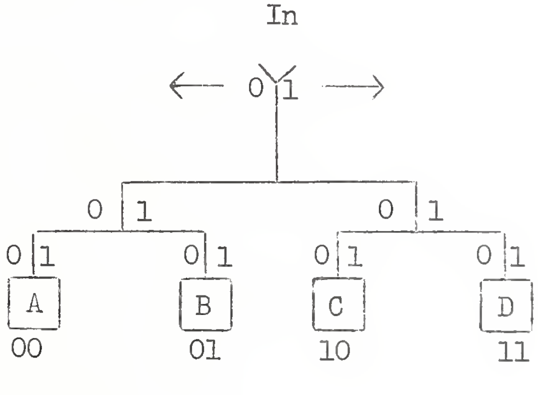
Information theory as developed by Norbert Wiener and Claude Shannon has been extended rapidly in recent years to many scientific fields. Psychologists recognized at once that the whole matter of statistical prediction turned upon the principle quite familiar in psychological statistics known as variance. From our previous discussions of psycholphysicas, for example, we measure the fineness of discrimination in lifting weights, comparing brightnesses, etc., in terms of the means and standard errors of the series of judgments made to find the value of a variable which can be discriminated half the time as just preceptably heavier or lighter than a standard weight.

The calibration of any observer thus becomes a matter of the amount of variance in his judgments of the variable compared to the standard. The measure of his precision h is equal to 0.4769/PE, where PE is the probable error, and the probable error of the mean of his judgments is equal to 0.6745 times the sigma or standard or root mean square error of the judgments.

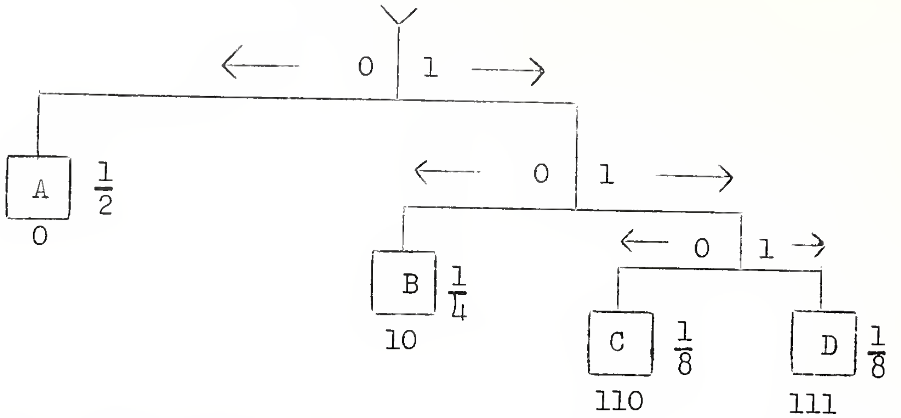
In a very similar fashion the communications engineer said that whatever part of a message he could predict, he need not transmit. And Wiener and Shannon showed statistically that ordinary 'messages' such as speech, music and pictures, are highly predictable. And in so far as this is so he can make his transmission channels more efficient by omitting the redundancies and transmitting only that which is essential.

This of course at once suggests the extent to which an efficient coding system can be devised. Suppose for example we had a four letter alphabet. The engineers assume that if each letter is equally likely to appear in the 'message' he may set up a binary-digit (bit) coding scheme like the following:



Thus from the input In the 0's and 1's show the constraints or sign posts enroute to the destination, that is any one of the four letters. The word C A B
then becomes 10 00 01
and only two symbols 0 and 1 are needed.

If the probabilities are not all equal and he has a system in which there are half A's, one fourth B's and one eighth each of C's and D's, then he would work out a cording scheme like this:



Now to call a cab you would send 110 0 10

You can draw a similar scheme for the 26 letters of the alphabet which shows that there are $\log_2 26$ or 4.7 bits per letter. It is interesting that Shannon, studying English writing, found that only about 1 bit of information per letter was carried by the writing.

By this time you may be wondering if information theory or communication theory is not another of those great forward strides made only occasionally in science but the consequences of which are like DFaraday's invention of the induction motor, or the discovery of atomic fission. But wait. Coding and transmission of information was old long before Wiener and Shannon were born.

In October 1832 an artist, Mr. Samuel F. B. Morse, invented a means of sending electrical impulses over a wire to convey information. On May 24, 1844 on a wire from Washington to Baltimore (40 miles) he sent the famous message "What hath God wrought?". Morse used a stylus which he called a "portrule" to indite the dot-space-dash signals on a paper tape. This same year Alfred Vail noticed that sounds could carry messages and so the telegraph "sounder" was introduced. Nowadays, that is since about 1920, most messages are sent by teletype, automatic printing, facsimile, etc.

Morse it was however who sent up the code, still used today.

Look at the following table. It contains the frequencies of occurence in English of the 26 letters tabulated from about 25 million words.

Morse code	Letter	Frequency
•	E	1000
—	T	640
• —	A	629
• •	I	577
• • •	R	556
• •	O	556
• • •	S	531
— •	N	508
———	L	356
— • •	D	320
• • • •	H	316
• • •	C	290
• • —	U	289
— —	M	226
• • • • •	P	199
— — •	G	170
• — •	F	170
• • • •	Y	148
• — —	W	129
— • • •	B	124
• • • —	V	97
— • —	K	59
• — • •	X	25
— • — •	J	22
• • — •	Q	21
• • • •	Z	10

E is the most frequent letter in English; T is found less frequently in the proportion 640/1000; and Z occurs 1/100 as often as E.

The dot took 1/24 second and the dash 1/8 second. Note that the T and the L are both one dash, but the L was made 5 units longer to distinguish it.

Note the simplicity of the coding of the first 8 letters in the order of their frequencies, that is E to N. Note that half of the most frequent 8 letters are on the top row of your standard typewriter keyboard. And S L D and H are in the second row.

There are many sounds coming to our ears while listening to dots, spaces and dashes and these may have no contribution to the message. The term noise means the ratio of signal to noise, and to us this sounds precisely like the thing we speak of as ground and figure relations, contrast effects, etc.

Psychologists, many of them in fact, have been busy not only in examining information theory but are testing it experimentally. What are the limits of our capacity for processing information?

First we must understand that our h factor or measure of precision of an observer is derived from quantal measurements. Variances are always stated in such terms. But in information theory the amount of information is a dimensionless quantity and can be extended to situations where we have no scale or metric. Thus experimental situations can be compared where it would be stupid to compare variances based on incomparable metrics. How bright must the flash of lightning be to be twice the intensity of the loudness of the thunder?

The amount of information in a system depends upon the amount of variance, that is, in the input. The amount of transmitted information depends upon the ratio of input to output. If we think of our sense organs as communication systems we can determine experimentally the output information as we change the amount of input information. For example Wherry showed that more than half of what we mean by "visual acuity" is dependent on something other than "resolving power." This something else was identified, by a complex factor analysis procedure, as what we know and recognize as visual form perception. König bar acuity is one thing; Snellen type is something else. And, we must therefore remember that each of us, in the black box, do a job of coding and recoding which will be in terms not of immediate input but of the residual after-effects of previous training and experience.

Laboratory studies, many of them, on the sense organs and their discriminations have shown that for pitch, loudness, position of a spot, tastes, colors, etc., the number of bits of information vary from about 1.9 to 3.25 and the number of discriminal steps runs about 5 to 7. This is also the classical "span of attention" and the span of immediate memory. Such studies point up one inescapable observation. Input probabilities, whatever else they may show, and they may show many important things, yet leave us with the fact that output information, meanings, acts, must be dealt with in another way.

Perceptual facts demand a further factor in the equation. This, some of us have recognized and dealt with, for a number of years. It is the fact of grouping. Professor Miller (Psychol. Rev., 1956, 63, 97) has written an illuminating paper in which he calls this function "chunking," that is grouping the signals into larger and larger "chunks." This is precisely what we do when we read; when we see forms. It is this skill in grouping which we have tried to emphasize over the years is the cardinally important function trained by the short exposure, by the tachistoscope. That is because, as Kohler, Wertheimer and others have shown the way, in weakly and poorly organized fields figures tend to be weak and the "parts" as dissociated as conditions will permit. Yes, visual training is something more, much more, than merely training vision. It is training to see; to understand; to live to the fullest measure of capability.

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October - 1957

Series 18 No. 1

The plan of the last two volumes of this series was to introduce the problems, methods and results of work in psychophysics, or intensity discrimination, preliminary to some further consideration of the perception of space and form, and of time and motion.

We reached the point of a brief introduction to modern communication or information theory. Then came the request, suggestion or proposal to write a series of papers dealing with the great experimental and theoretical contributions to vision made by psychologists and related scientists in the past. These papers to furnish the setting, background or foundation for present theory and practice.

This new assignment necessitated a rather radical change of my plan, and aroused some question or doubt as to my ability to do it. Who and what is to decide what were the really great and influential contributions to vision?

If one were to select twenty psychologists of outstanding competency and have them list their choices of the dozen or so greatest contributions to vision I am reasonably sure that, except in a few instances, there would be little agreement. This, of course, is understandable in terms of differences of training, interest, point of view, etc. There would be little question and almost unanimity about some of the great contributors. But, what ones, and the rankings on a scale of importance, is another question.

Since it seemed to be up to me to make, according to my lights, a list, I wrote down some forty five names and titles from which the ten or a dozen judged most important could be chosen. I tried to select on the basis of works which had exerted unquestioned influence on the better understanding of vision. To do this it seems imperative to follow, at least roughly, a chronological order. At once the question arises, how far back shall one go?

Psychology split off from the parent philosophy and started working as a division of science about 1885. With the separation came important (and some harmful) legacies from philosophy. I have decided to start this series with an early and great contribution to vision of a philosopher, the Irishman, George Berkeley, born March 12, 1685 and died in the winter of 1752.

After the Master's degree at Trinity he served as Tutor there from 1707 to 1712. In the year 1709 he published his first book. It was really a monograph of some 85 pages. The title: An Essay Toward A New Theory Of Vision.

In order to appreciate the greatness and significance of this bit of writing it is first necessary to recall that in 1709 the prevailing view (as is probably true today) among "educated" people was an "unsophisticated dualism."

In such a view, the world is comprised of two kinds of things: matter, physical, material, "real" objects; and, mind, spirit, conscious processes.

Berkeley, an idealistic philosopher, denied and could not accept the dualistic hypothesis, holding that material things do not exist. He denied that one could see, touch and hear and hence know the existence of material or "real" things. He held that materialsm is self-contradictory and leads to the conclusion that a material object has no stable or constant nature of its own. To illustrate his point Berkeley cites a well known demonstration. If one prepares three beakers of water, the one on the left cold at about 9 degrees Centigrade, the one to the right warm at 40 degrees and the middle one neutral at about 30 degrees. If the two hands are adapted for a few minutes in the right and left beakers then immersed in the neutral one then you directly perceive that what the dualist calls material water is both hot and cold at one and the same instant; yet actually to an unadapted hand the middle beaker is neither hot nor cold.

Berkeley held that the dualist is naive, and cannot defend the doctrine that the material world is fixed and permanent. He preferred the position of the idealist who holds that things are ideas and are characteristically and notoriously changeable. Material objects may be seen as large or small, near or remote, depending on where, when and how we see them. Fixity of size or form of objects thus was denied as was the distinction of Locke and Descartes of the primary and secondary qualities of objects. These, Berkeley held, are "inseparably united" in the physical object. What we see, he said, is not the "colored and extended, but the colored extended object."

For Locke and Descartes the secondary qualities were mental. Berkeley held that, by parity of reasoning, one had to conclude that the primary qualities, extension and motion, are mental also; that we cannot claim that material objects are perceived directly, or, in other words, "the objects of our direct sense-consciousness are themselves percepts."

The materialists claimed further that though we perceive only what is mental, that is, our own percepts, we must infer that the "causes of these percepts are existent material objects."

This Berkeley could not accept. He objected on the ground that "causes must be held to resemble their effects" and that a material, non-mental thing cannot be conceived as the "cause" of a percept, which is mental. Causes are active, whereas matter is "passive and inert." So he rejects the theory "because no inactive thing can be a cause at all," and matter cannot be inferred to exist as the cause of our percepts. "cause itself is a form of experience" said Berkeley.

Berkeley based his idealism on the appeal to our own basic consciousness. Whatever we experience is part of our own active experiencing and so must be classed as mental, said he.

I should point out that all this is but a brief and incomplete attempt to give a quick sketch of Berkeley's point of view. It is done here as necessary to a fair understanding of the position he takes (in 1709) in the Essay Toward A New Theory Of Vision.

Now, turn back if you have a complete set of these papers to Vol. 11, No. 5 (March 1951). There you will find a paper which is also a historic and monumental contribution to vision -- a description of the famous experimental observations of Christian Scheiner, the Jesuit monk, published in 1619, just a little less than a century earlier than the appearance of Berkeley's famous Essay.

I mention this here at this time because I want you to see that clever and important observations and experiments on vision were made long, long before anyone knew that the body is made up of cells (about 1862) or that the nervous system is composed of neurons (discovered by His in Germany and Cajal in Spain in 1892). Berkeley, strange as it may seem to us, knew the geometric, materialistic and mathematical optics of his time and knew it well. He could not reconcile its teachings and "explanations" of distance, size, form, position, etc., with the operational, experiential observations of the whole man living in the world as an individual. Like Gullstrand, he could not accept the grossly oversimplefied diagrams of the optics writers who pictured the eye as a camera. One can only surmise how far ahead of his time this clear thinking Irishman was, and at the same time wonder why so few in modern vision work have ever taken time out to read and think about the Essay!

Let us look at some of his observations and reasoning written some twenty years before he arrived in America in 1729 at Newport, Rhode Island.

In some instances I shall quote directly from the Essay; in others I shall have to condense and paraphrase.

Opening the Essay, Berkeley says; "My design is to shew the manner wherein we perceive by sight the Distance, Magnitude and Situation of objects; also to consider the difference there is betwixt the ideas of sight and touch, and whether there be any idea common to both senses."

"Distance, of itself and immediately, cannot be seen. For distance being a line directed endwise to the eye, it projects only one point in the fund of the eye, which point remains invariably the same, whether the distance be longer or shorter."

"The estimate we make of the distance of objects considerably remote is rather an act of judgment grounded on experience than of sense."

I strongly urge the readers of this paper to get a copy of the Essay and read and carefully ponder the analysis of the roles played by blurring, conjugation, focus by lenses, etc., and the complete rejection of the "classical" explanations of size and distance found in modern treatises on geometric optics. These are found in sections 29 - 40 of the Essay and cannot be condensed in our limited space. Berkeley concludes that "I neither see distance itself, nor anything that I take to be at a distance. I say, neither distance nor things placed at a distance are themselves, or their ideas, truly perceived by sight."

"Looking at an object...from what I have formerly observed, determine me to think that if I advance forward so many paces, miles, etc., I shall be affected with such and such ideas of touch." What he sees only suggests to his understanding that, after having passed a certain distance, to measure by the motion of his body, which is perceived by touch, he shall come to perceive such and such tangible ideas...usually connected with such and such visible ideas. Clearly here is the forerunner of a motor concept of vision, yet for two and a half centuries how many scholars took the trouble to test the hypothesis experimentally? Very few.

Further on he argues that hearing, sight and touch are unified in perceiving the thing out there. It is not a sum or mosaic of differing modal sensory impression but that which every competent student of visual perception knows well: We see things as unities or not at all. So neither Von Hornbostel's "unity of the senses" nor Stratton's "external reference" were either new or original. Berkeley pointed them out clearly in his famous Essay two hundred years earlier, but hardly anyone paid any attention. Optics was so rigid, so "scientific" so blinding to the real facts of seeing.

Next time let us look at his treatment of the important problems of the "Magnitude and Situation of Objects."

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I can only speculate as to the kinds of reception Berkeley's ESSAY TOWARD A NEW THEORY OF VISION received on the publication of its some 85 pages in the year 1709.

Without doubt there must have been those, who like today, "turned up their noses". There must also have been those who reacted like one rudely and suddenly awakened from a peaceful nap -- awakened to the stark fact of there being no clear cut and satisfactory way of finding, in the geometric optics, of suitable and defensable "explanations" of phenomenal experience, visually. Perhaps here, in the thought provoking Essay, was a new province for science, unexplored but beautiful, challenging and promising.

Continuing his argument, briefly sketched in the previous paper, Berkeley said "From what has been premised, it is a manifest consequence, that a man, born blind, being made to see, would at first have no idea of distance by sight: the sun and stars, the remote objects as well as the nearer, would all seem to be in his eye, or rather in his mind. The objects intromitted by sight would seem to him (as in truth they are) no other than a new set of thoughts or sensations, each whereof is as near to him as the perception of pain or pleasure, or the most inward passions of his soul. For, our judging objects, perceived by sight to be at any distance, or without the mind, is entirely the effect of experience, which one in those circumstances could not yet have attained to."

Continuing, he says, "one blind from his birth, being made to see, should stand in need of no new experience, in order to perceive distance by sight. But that this is false has, I think, been sufficiently demonstrated."

In substantiation we may call attention to Von Senden's monograph, describing the experiences of more than one hundred cases where sight was restored surgically; George Campbell, and all the many others who by corneal transplants, etc., have been made to see, but only after proper training and experience. The surgical and mechanical repair of the optical receptors, making conjugate foveral vision now attainable, leaves the person not much better visually than he was before, until he is trained. Campbell, before training but after his operation, looking out of a fourth floor lab window at a street at a right angle to his line of regard, was told to "Look at the curbstones; which one is nearer to you"? His answer: "Neither one; one is higher than the other."

Campbell without any lenses has some 3 1/2 diopters of accomodation. Accomodation, therefore, like distance, cannot be purely a lenticular function. As Leiri pointed out many years ago, in accomodation, the retinas, central distributor and effectors must also play their roles.

Berkeley than discusses the Magnitude (size) of objects. "It is the opinion of some," he said, "that we do it by angles, or by angles in conjunction with distance."

"But neither angles nor distance, being perceivable by sight...as we have shown, lines and angles not to be the medium the mind makes use of in apprehending the apparent place; so neither are they the medium whereby it apprehends the apparent magnitude of objects."

The mind, says the dualist, compares "the angle under which it is seen with its distance, and thence infers the magnitude (size) thereof."

"What inclines men to this mistake (beside the humour of making one see by geometry) is that the same perceptions or ideas which suggest distance do also suggest magnitude."

Berkeley then continues "I say, they do not first suggest distance and then leave it to the judgment to use that as a medium whereby to collect the magnitude; but they have a close and immediate connexion with the magnitude as with the distance, and suggest magnitude as independent of distance, as they do distance independent of magnitude."

And, "it is also evident that confusion or faintness" (by which is meant blurring by lenses or image deposition - S.R.) "have no more a necessary connexion with little or great magnitude than they have with little or great distance," because, "if it were not for experience we should no more judge a faint or confused appearance with great or little magnitude than we should that it was connected with a great or little distance."

Nor does "great or small visible magnitude have any necessary relation to great or small tangible magnitude -- so that the one may be certainly and infallibly inferred from the other."

Animals learn to take the visible size, position, distance and velocity of objects and interpret them in terms of the "damage or benefit which is like to ensure upon application of their own bodies to this or that body which is at a distance."

We see distance and magnitude, was Berkeley's argument, "in the same way we see shame or anger in the looks of a man. Those passions are themselves invisible."

"It is through 'experience'", said Berkeley, "that we must learn to interpret in terms of our actions the immediate objects of vision." Vision thus for him was a triggering device, the first term in a most highly complex series of events and could not have the remotest resemblance to the workings of a mirror or camera.

After a somewhat lengthy consideration of the moon-horizon "illusion", Berkeley concludes that visible size is always judged in terms of "tangible extension," that is, in terms of tactual and kinaesthetic frames of reference. In carefully searching the Essay, I was surprised to find no hint or mention of the important difference between the active and passive touch and their relative relations to, e.g., binocular vision. But, 1709 was 1709, and had I been living then like the great majority I probably would not have been able to read and write.

Considering the relative apparent sizes of the moon, Berkeley objected to Wallis' explanation, which was based on differences in the subtend angles at the eye, on the ground that the angle subtended by the moon is the same both at zenith and horizon, "nor do they suggest aught external (i.e. angles) whether distance or magnitude, otherwise than by habitual connexion, as words do things."

This, he holds, is "a clear instance of the insufficiency of lines and angles for explaining the way wherein the mind perceives and estimates the magnitude of outward objects."

Lines and angles are necessary, for "there is a use of computation by them -- in order to determine the apparent magnitude of things so far as they have a connexion with and are proportional to" our tactual -kinaesthetic frames of reference.

"Quantities of the same kind may be added together to make one entire sum," but the impressions of sight and touch are always and forever different, hence are not added together in the ordinary sense in the act of perceiving.

Here Berkeley appeals to speech and language as the integrative function. He hints at the idea of syncretism or wholism as the basic mechanism of perception, although he does not use these names, and he shows that to him at least, things seen and touched get meaning only in terms of the organism-environment actions which unify them. Since "visible figures are called by the same names as the respective tangible figures suggested by them", just as "written words do sounds" we may note the emphasis placed by Berkeley on language in perception.

In 1709 it was well known that any external object was optically imaged on the retinas upside down and backwards.

So the position of any object could not be given by vision alone. Again here he cites the blind, with sight restored, and suggests that to him it is clear that from infancy to adulthood the seeing must learn position, size, form, motion and distance "by experience". They are not purely and only visual.

Interestingly enough Berkely, like many a modern takes for granted that when one says "by experience" everyone is perfectly clear as to what this means. That this is surely not the case will be developed in subsequent papers.

Berkeley's objection to any attempt to understand vision or the seeing of objects purely in terms of physics and mathematics was opposed then, as in the doctrine now, by many. He pointed out that just as it is virtually impossible to hear the sounds of spoken English words without the understanding of their meaning, so he concluded that "neither the abstract or visible extension makes the object of geometry; the most discerning of which may, perhaps, have created some difficulty and useless labor in mathematics."

It certainly took courage thus the present a new and very different theory of vision in 1709 since the prevailing theories then were almost wholly those of geometric and physical optics.

Physiology came onto the scene about a century and a quarter later with Johannes Müller, between 1832 and 1840, setting forth the idea that the methods and concepts of physics could also be used in the study of biological problems which, to him, had no room for vitalism and animism.

Clearly Berkeley's Essay challenged the prevailing "explanations" of visual phenomena and said flatly that physics and geometric optics, however valuable their contributions, had no satisfactory or defensable explanations of how we see space, form, size, position, motion, and how the several different "intromissions" from the differing sense modalities could be and were unified in the percept.

To appeal to learning and experience was a bold stroke. Most modern students of the problems of size-distance relations (size constancy) seek their answers in terms of geometry. But what happens when a pronounced micropsic, through proper training, comes to see sizes correctly at all workable distances? The "lines and angles" have not changed. Even when we do change the lines and angles deliberately by the addition of lens powers, the apparent sizes remain unchanged.

So, even though you and I may not be able to join Berkely in his denial of the existence of the "real" physical world, which we must postulate if we are to work as scientists, yet we must express our great debt to this great Irishman.

It is well to remember that often times "The rebel of today becomes the patriot of tomorrow."

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The difference between the scientific and non-scientific descriptions of things and processes in nature lies in the differences in methodology. The scientist formulates a set of postulates to govern his activities and abides by these principles according "to his lights." He realizes fully that they are always in process, that is that with new discoveries and broadened understanding, he may need to abandon one and set up another better or more comprehensive postulate to take its place.

The parent science of physics gives us elegant examples. Think of the physics of Isaac Newton and of the basic and fundamental changes in problems, methods and interpretations wrought by the development of quantum mechanics. Similar changes in point of view, enforced by the growth and development of science in all fields, could be cited abundantly in chemistry, biology, and psychology,

So to gain a real appreciation and insight in any province of science it is obligatory to have at least a reasonable familiarity with the developmental history of that field. The truth of this statement becomes the more apparent when we learn that almost no important advance is or has been made by a single individual working alone. The fact that the $E = MC^2$ concept of Einstein was the joint product of his wonderful creative thinking and the mathematical genius of Lisa Meissner, plus the accumulated knowledge of men like Bohr, Fermi, Plauck, Maxwell, Gibbs, and at least a score or more others. This is one of the splendid things about science. It is not for little, selfish persons. The search for truth is the guiding light. Once the young scholar sees and feels it sincerely he knows a kind of peace and satisfaction in his efforts unmatched except perhaps in the dedications to the arts, religion, etc.

I warned those who read these papers that the task of selecting the great works and workers who have made important contributions to vision, and reporting briefly thereon, was not an easy one. You may not agree with my choices. That is your privilege. My selections follow partly an historical and partly an ideological sequence. For that reason, in this paper, the third of the series, I should like to review the work of a man who was both a great physicist and a great psychologist --Ernst Mach.

Mach was born in Moravia in 1838. He was educated at Vienna and at 26 he was Professor of Mathematics at Gratz; at 29, Professor of Physics at Prague, and at the age of 57, Professor of Physics at Vienna. He died early in 1916.

Think a bit of the cultural climate in which Mach grew up. The years from 1840 to 1880 were tremendous years in the history of science. The steam engine, the electro-magnet, telegraphy, the induction motor, the cell theory in biology, to name but a few, were discovered, invented and produced in this period.

At the very time of Mach's birth, Weber and a bit later Fechner had developed the epochal 'fundamental formula' of psychophysics.

Mach, like the two princes of Serenar, was born in the atmosphere of the problem of the relations of physics and psychology. In a word he was at the right place at the right time.

Very early in his life he agreed with Berkely that all existence is sensation; but radically disagreed as to what constitutes sensations. After much experimenting, thinking and writing, Mach wrote, in 1888, the first edition of his Beiträge Zur Analyse des Empfindungen

(Contributions to the Analysis of Sensations) which I believe is the best single expression of his psychological work. Here he adopts a point of view which is described as a monistic or universal physical phenomenalism. The world is not matter and mind. Mind (i.e., sensations) was merely a physical function of an unbelievably complex electro-chemical system all experienced and localized in the self or ego as awareness. The body and the self or ego were part of the physical universe and gained definitive status as a self because the body (sense organs, brain and effectors) could thus extend in time (memory) the sensory experiences and give them syncretic unity and continuity.

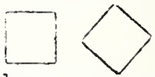
Parenthetically, remember that Mach was 54 years old when in 1892, W. His, in Germany, and Ramon Cajal, in Spain, independently discovered the neurone. Yet the Contributions to the Analysis of Sensations, his postulates on psychophysical and phychological problems, stating his point of view, appeared in print four years before this!

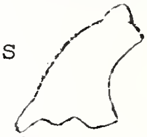
So much for a general statement of Mach's position - the diametrically opposite of that of Berekelyan idealism.

Let us now look at some of the experiments on visual problems made by Mach and the influence on subsequent work on such problems as visual apparent movement, form and space perception, stereopsis, etc.

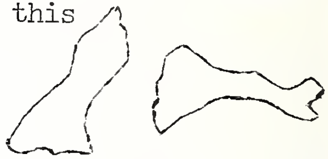
But first note the close similarity between the view of Mach, expressed in his physical phenomenalism, and the isomorphism of Köhler and Wertheimer, who held that no real differences exist between the molecular processes of physiology and biochemistry in the neuromucular systems and molar processes in perception. The latter is only the former in extension.

If one accepts this view, which one must if he thinks in terms of the organismic rather then cell theory as basic in biology, then it is clear that also a strong movement in the same direction was afoot in psychology well before the advent of Gestalt theory about 1912. There were of course other strong advocates of wholism as contrasted with elementarism; even as early as Thomas Aquinas, Von Ehrenfels, Husserl, and Meinong, but Mach met the issue squarely with a clear expression of a physical monism.

As to form perception Mach showed that if one sees these two figures  geometrically congruent, "they can never be recognized as the same without mechanical or intellectual operations."

If a figure like this  is repeated say six times in a horizontal row, we get a "peculiar, agreeable impression and recognize at once and without difficulty the identity of all the figures."

But if we use two such figures turning the right one like this



then, says Mach, "Their identity of form is not recognizable without intellectual assistance. Continuing and extending the observations, he concludes that direction is very important "as the geometrically congruent is not necessarily physiologically (optically) congruent, nor geometrically symmetrical necessarily optically symmetrical, analogously the geometrically similar is not necessarily optically similar." Only when two forms are placed beside each other in the same relative positions will they also appear optically similar.

When two forms, say triangles, have their sides in the ratio 1:2 "we do not recognize this simple relation between the two immediately, but intellectually, by measurement. If the similarity is to become optically perceptible, the proper position must be added..." again if a constant amount is added to each side of one of two identical triangles, "the two do not look at all alike. Similarly all conic sections do not look alike although they stand in a simple geometric relation to each other; still less do curves of the third order exhibit optical similarity."

So, "since we are immediately cognizant

of the similarity of figures lying in similar positions, and are also able to distinguish at once the special case of congruity, therefore our space -- sensations yield us information concerning identity or difference of directions and equality or inequality of dimensions."

Space sensations, said Mach "are connected in some way with the motor apparatus of the eye." The motor apparatus is symmetrical with the median plane, "hence symmetrical movements of looking will be connected with like or approximately like space sensations. Children constantly confound the letters b and d and p and q but not b and p or d and q. But, "the whole body, especially the brain, is affected with a slight asymmetry."

Mach first expressed the motor basis of space and form perception in 1861. The reason we don't confuse the sight of something at distance with something here at hand he says is because the distant object causes different sensations than the near. "They cannot be confused, because the motor apparatus is asymmetrical with respect to a plane perpendicular to the direction from front to rear."

Werner for example showed that a luminous vertical rod seen in a dark room was judged vertical, but when the skin of the neck and shoulder had its temperature lowered by a cold towel, the rod was inclined from 8 to 10 degrees in the opposite direction. Change in tonus, i.e., tonic assymetry must be written into the equation defining the vertical.

Harmon's studies of asymmetrical illumination of the visual fields of young school children are so familiar that we need only to call attention to his important findings.

More interesting and important were Mach's keen experimental observations on the problems of retinal correspondence, stereo depth, visual apparent movement and the role of the vestibular functions related to vision and to certain of the visual illusions.

These we shall summarize in our next paper. The English translation of The Analysis of Sensations is a 6th edition. My copy was by Open Court Pub. Co., Chicago, in 1914. Many references to Mach's contributions will be found in Boring, History of Experimental Psychology and Boring, Sensation and Perception in the History of Experimental Psychology, both of Appleton Century. The original German papers are available only in larger libraries.

Two things stand out thus far: Mach proposed that a single scientific set of principles are sufficient for physics and phenomenal psychology; space perception cannot be adequately treated by the geometry of lines and angles, since, he points out that stresses in the visual system and the motor processes in achieving some suitable equilibrium within the organism must also be treated in any discussion of visual space and form perception.

Neither the Boring or Murphy histories of psychology attach as much importance to Mach and his work as I have in this and the next paper. If I am wrong time only can show that the things Mach proposed are live problems for research today and without doubt also will be with us tomorrow in the formulation of visual understanding which leads to producing the maximum of functional visual efficiency. Today I do not believe we are doing this as well as we should. We do not know enough about the fundamentals. Practice is never any better than its supporting theory.

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Ernst Mach held essentially that "man, born of woman, is of the earth earthy..." Our bodies are electrochemical systems of the most extensive complication; the operations of these organic systems are only partly understood and controlled. The fact that a man can see and perceive a shaped colored object and can know and predict his and its behavior in coaction differs only in degree from what happens when you sound simultaneously the notes C - E - G on a piano or better still when you precede and follow the C - E - G pattern by other patterns which constitute a melody.

When two tones are sounded simultaneously, such as C - G, you hear Tartini tones, difference and summation tones. If the frequences are 256 and 320 you hear four tones or even more, the two, plus one of 576, and a low one of 64 cycles per second, and if your ears are good enough, the second and third order sums and differences of these frequencies. If now we substitute a good microphone for the ears and pass the frequencies into a Cathode ray oscilloscope and photograph the wave pattern, there are never more than the two original frequencies in the air. This means merely that the observer has an acoustic mechanism which supplies the other components of the compound sound he hears. He hears more than is supplied, or can be predicted, in advance of experience, by the "stimulus."

This is known as epiphenomenalism. It is the concept in mathematics of functional numbers where 2 plus 2 may equal 1, or 2, or 6 1/2. It is seen, for example, in Fechner's paradox, familiar to all who work in vision, where if the right eye has a bright illumination and we introduce a weaker illuminance to the left eye, the right field at once appears less bright. It is the principle of Lloyd-Morgan's Emergent Evolution.

As one may quite naturally expect, such phenomena in nature have occasioned a very considerable amount of disagreement, argument, and debate. Without denying the existential reality of the phenomena, the interpretation and alignment within a theoretical system or framework was quite another matter.

One of Mach's chief contributions was to bring some order out of the confusion as to the fundamental visual problems of the perception of form and particularly of space.

Mach pointed out that Johannes Müller "put forward with great lucidity the theory of identical retinal positions" which could be traced back as far as Ptolmey. Müller thought that the retina "has sensations of itself in its own activity" and that visual space was "immediately given." The arrangement of the parts of the retina gave direction, but, unable to find a satisfactory accounting for distance on such basis, ascribed distance to "an affair of the intellect."

But shortly after 1838, when Wheatstone invented the stereoscope, it became evident that things could be seen singly, tridimensionally and with different degrees of depth according to the amount and direction of the decentration, "not only when the images fell upon identical parts of the retinas, but also when they fell upon other parts, provided the difference between the parts was not too great."

So, the doctrine of identity or of corresponding points was held to be unsatisfactory and psychological "explanation" as to how we see things as having depth was sought.

Brücke sought a way out in his theory of successive fixation in spatial vision only to have it shown by Dove that in instantaneous exposures too short for any successive fixation perfect stereoscopic images could be seen.

Then Panum came along in 1858 "taking his stand on the phenomenon of binocular rivalry and the prominent part played therein by contours" came to the conclusion that our ability to see things as having depth depends "on a reciprocal action or synergy of the two retinae and that the sensation of depth is an innate specific energy." Panum even held that "this depth corresponds to what is given by means of lines of projection."

Strange indeed that Panum came so close to and yet so far from the best modern version of depth. Washburn showed in the late 20's and early 30's that if one stops figure alternation (i.e., what was called retinal rivalry) then vision ceases to be tredimensional and becomes planar.

But when one reflects upon the limited understanding of biological and psychological science in 1858 one can only honor Panum. He made a good try, but to say that depth perception is "an innate specific energy" is merely raising the unanswerable problem of "what is an 'innate specific energy' and how does it do what you say it does"?

Hering came along then four years later and proposed a different and somewhat better solution to the problem, but also one which fell short of the mark.

Hering held that the immediately given, i.e., the purely optical, space must be completely distinguished from the conceptual space which results from the organizing and structuring of "experiences of a special kind."

By many experiments Hering came to the conclusion that the direction, that is, the spatial position of an object is different from the line of regard between the object and the "retinal image." The two eyes see the same as the single cyclopean eye, midway between the two. With symmetrical convergence if we focus on a point on the window pane we see this point in the median plane, but at the same time we also see behind it in the same plane objects lying a long way to one side.

In stereo experience we still see objects in front of us even when there is only a slight vergence of the axes of the two eyes, even though the directions of projection no longer leads to these objects. This of course is perfectly obvious, just as the facts of size constancy have shown that these and other facts of binocular space perception cannot be satisfactorily "explained" by the theory of projection, that is purely on the basis of the lines and angles of geometric optics.

For Hering "corresponding" retinal points have identical height and breadth values; symmetrical points identical depth values and the latter increase from the outer edges of the retinas inward. When similarity of the monocular images causes them to coalesce or fuse the binocular image contains the mean value of the depth values of the single images. The two eyes were then functionally a single organ for Hering. This synergy of the two eyes rested on an "innate anatomical foundation" and anteceded the later discovery of the Gestalt psychologists that binocular, tridemensional vision is simpler and more primitive than planar or two dimensional vision.

Now we pass to the reasons why Mach's contributions are so important. He was the first to emphasize as of first order importance visual space as a dynamic and not a static phenomenon. To quote "It looks as if the visual space would turn into a second space, which is held to be immovably stationary, although this second space is characterized by complete absence of visibility. The space which is built up from motor-sensations seem, in fact, to be the original space." Chicks fresh hatched peck at "everything that excites its attention." New born human beings have "a lower degree of maturity, but otherwise the conditions must be essentially the same. Panum has brought out this point."

One of Mach's main contributions arose from studies, like those of Dreyfuss on guinea pigs whose labyrinths or semicircular canals were destroyed, then the animals were placed on a rotation table. They remained motionless in one place, showed no displacement of the vertebral column, no nystagmus of head or eyes. Normal pigs stopped eating on rotation. The ones with both labyrinths destroyed continued to eat regardless of the direction of rotation.

Mach held that experiments like those and others show that "They are far from meaning to imply that the labyrinth alone furnishes the sensations necessary for the maintenance of equilibrium; rather it cooperates to these and with the sense of pressure (skin) and the muscular sense, as well as with the sense of sight."

Thus to Mach rather than to Von Hornbostel we owe the origination of the concept of the unity of the senses. Mach's experiments of visual apparent movement, and upon the optical illusions helped significantly to set the stage for the experimental and theoretical psychologist to extend his views on vision beyond vision by pointing out its dependence on other more fundamental and primitive functions, that is from movements, from the skin and kinaesthetics, from both the cochlea and vestibular functions and finally from the memory trace systems of the ego field in relation to its surrounds.

VOLUME 31 — OPTOMETRIC EXTENSION PROGRAM PAPERS — (POSTGRADUATE)

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PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshow, Ph.D., at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PSYCHOLOGICAL OPTICS

February - 1958

Series 18 No. 5

To get a clear and complete understanding of present day problems we have to know their history. Only when we have a reasonably good understanding of how, when, where and by whom a theory, an instrument, or a method was developed, and the changes which have taken place in it throughout the years, can we really apprehend the problem in its true lights and hence come to some defensable decision as to what we must do about it.

No concept has greater importance for all of us than that of space. None has brought forth a greater variety of theories, practices and attempts to define space.

For example, space for Issac Newton was a "real receptacle, intrinsically void." For Descartes it was "the essence of bodily substance." Spinoza thought it was "an attribute of substance." Berkeley held that space is "a mental construct, due to coordination of the sensations, especially sight and motion." Kant thought of it as "an a priori form into which sensous experience necessarily falls," and finally Aristotle defined it as "that without which bodies could not exist, but continuing to exist when bodies cease to exist."

So, among the greatest of the philosophers there was little agreement and certainly no clear cut workable definition of space, for to define anything we give it limits, or spatial boundaries.

Genetic or developmental psychologists, Preyer, Shinn, Minkowski, Peiper, Baldwin, Gottschaldt, and more recently Piaget, based on scores and scores of experimental and observational studies on development from the neonate to the adolescent are unanimous in affirming that nothing in the behavior repertoire is more basically and fundamentally important than the development of good space perception. Almost all competent authorities agree that a part of the problem is nativistic, that is that some part of space perception is unlearned and must therefore be due to the inherited biological structures, and that the remainder must be due to the learned structuring and organization of experiences. The illiterate Australian 'tracker' in his native habitat could easily make the best and most observing of us still look weak and inefficient.

Late in a beautiful autumn afternoon, a man (me) sits in his garden "neath the shade of the old apple tree." By his side sits Hans, his dachshund. Above, in the tree, are a pair of birds - cardinals. In the grass, near Hans, an ant struggles through the dense forest of the grass, carrying home to her nest, three or more meters distant, the remains of a deceased insect.

Five animals all living and doing things, "according to his lights", in the same geographical or geodesic environment, yet each of us living and doing things in the utterly different spaces of our individual and several behavioral environments.

It is interesting to speculate on what space must be like to the male cardinal, with his laterally set eyes and no overlap of his visual fields; his directional responses to polarized light - something we humans cannot do and know little about. And the ant, through the trackless forest of the grass, yet someway finds her way home.

But we must forego temptation to speculate and get on with the main business of this paper - a review of the scientific study of our human, binocular space world.

In several previous papers of this series (Vols. 8 and 9, 1947 and 1948) I devoted one paper to the famous experiment of Christian Scheiner, a Jesuit monk, who in 1619 published his findings in a paper of great importance. It gave us then as now an understanding of what has been called "physiological diplopia," and it set forth clearly and understandingly, as anyone can observe by repeating his experiments, the underlying principles of human, binocular, stereoscopic vision.

But Scheiner was not the first. The problem goes back to Euclid's treatise on Optics and Catoptrics in the year 300 B.C., to J. B. Portra in 1583, to Leonardo Da Vinci in 1651. Too we owe much to J. R. Smith in 1728, to W. C. Wells in 1792, and to H. Mayo in 1833.

All these, along with a list of others, were prolegomena to the invention of the stereoscope, in 1838, by Sir Charles Wheatstone (1802-1875), an English physicist and apparatus designer.

The principle of the Wheatstone Stereoscope was simple. The eyes looked straight ahead into two good mirrors, each set at 45° from the median vertical plane, thus viewing the left and right views set parallel to the median plane. The resulting projection was a binocular, stereoscopic three dimensional picture seen in the cyclopean position. This basic design is used today in radiology for stereo-x-rays, also in photogrammetry and cartography, and in certain industries.

But we owe, also, the stereoscope as a scientific instrument to another man, who in 1816 had invented the kaleidoscope and, probably inspired by Wheatstone's invention, he showed that by using appropriate prisms base-out, the same effects could be secured as by the mirrors of Wheatstone. This man was Sir David Brewster.

Brewster described his device in March 1849 before a meeting of the Royal Society of Edinburgh. Interestingly enough, British optical people were almost completely apathetic to Brewster's instrument, so after about two years of trying to interest them, he took his instrument to Paris in 1850, where it aroused immediate interest. There Duboscq and Soleil, optical technicians, replaced with a ground glass screen the opaque end of the instrument facing the eyepieces, thus making it possible to view transparencies with better contrast, color, detail, etc. A year later, at the Great Exposition, in London, Brewster's improved invention engaged the interest of Queen Victoria who "deigned to endure three minutes' exposures in order that the royal features might be fittingly recorded through a pair of lenses." When the British looked at their Queen in striking relief and tridimensionality, stereoscopy was really "made".

A final improvement of the Brewster instrument was made by Hermagis, an optician, who recognized that prisms were for many tiring to the eyes. In 1856 he constructed the first stereoscope made with complete and parallel achromatic lenses, plus spheres, and thus secured the double advantage of eliminating "ocular fatigue" and enlarging the apparent size of the pictures. Hermagis shrewdly realized the correct viewing distance at the principal focal distance by making the focal length of the eyepieces approximately equal to that of the camera lenses used to make the transparencies or prints.

Then a great American made another improvement, Oliver Wendell Holmes. He made the focus adjustable by putting the images on an adjustable bar and added the septum to prevent either eye from seeing the other's view.

So the parlor stereoscope of our grandparents, with its view of Niagara Falls, and the Grand Canyon, became the forerunner in the gay nineties of the radio and TV.

In the more modern times two further improvements were made. Maddox, in England, made one of these. His improvement was an ophthalmic one: He made the two images capable of decentration by means of a reversing screw, so not only could persons with limited stereo amplitude see three dimensional views, but the device could be used as a testing and measuring device to determine the limits of break and recovery points when the decentrations were made both crossed and uncrossed from the zero or ortho positions. But Maddox's device worked at only one position or setting, usually at far point.

To improve upon this defect the writer designed and built a mechanism consisting of a pair of adjustable tracks so that any decentration or any relation of "accomodation and convergence" could be maintained as the split stereograms were changed from far to near points or vica versa. This instrument now made possible several measures of visual space functions, and in an article in a leading ophthalmological journal, Dr. Paul Boeder, after a searching mathematical analysis, reported it to be an important advance in the history of instruments for the study and measurement of various aspects of visual space.

Then too there came into being stereo projection by means of polarized light and polarizing viewers, and things moved forward. For example think of the development of the Sonne system and the role it has played in our military efforts, as well as of the many uses made by stereo projection in research as well as in visual training procedures. We really have come a long way and have made it practicable and possible to subject visual space and form perception to rigorous experimental test and measurement. Thus scientific methodology rather than rational and logical speculation has been brought to bear upon the problem of visual space. The wonder is, as we look back upon its history, that with all our human ingenuity and cleverness, it has taken us so long to get this far. The end is not in sight.

In 1859, for example, Panum wrote a paper in which he recognized the necessary role played by what was then called "retinal rivalry" in stereopsis. He saw that "rivalry" was a function of contours and occured therefore when the two eyes were simultaneously stimulated by forms falling on "non-corresponding points" of the retina. It took nearly three quarters of a century to discover that unless alternation (or "rivalry") goes on there is no stereopsis but only planar viewing. This was a contribution of the late Margaret F. Washburn, brilliant American psychologist, who showed that in normal seeing alternation is going on all the time even though we are never aware of it. This is what Professor Köhler has called a "silent process".

Our laboratory has been able to show, among other things, that only figures, never grounds, alternate in stereo vision and that there is a critical frequency range below and above which there is no stereopsis. Is this important for a full and complete visual analysis? Some of us think so. Others, some optometrists and opthalmologists, think not. Time will tell, along with research done by those who have earned the right to pass judgment.

Berkeley was the first to point out that visual space perception, so far as size or magnitude is concerned, presupposes tactile or haptic space perception. Judgment of size depends on reference to the traces left by the experienced or trained active touch, plus the feedbacks from the muscles, tendons and joints. Such active touch learned from infancy on, gives knowledge of position and distance, relative to the body, and of form and of apparent size. Mach pointed out that the macula corresponds to the tip of the finger and that we are quite well able to distinguish whether the finger moves over an object or the object over the finger, just as it makes all the difference in the world whether the light image pattern moves over the retina when it is still or when following the complex movements of Listing and Donders, it takes up fixation.

To Ernst Mach, probably more than to anyone else, we owe the idea that our visual space - the "without which nothing" of our visual experience - is basically a function of the fact that we live and move and have our being in a behavioral environment that is always within the gravitational field. That is, body posture, the semi-circular canals, the kinaesthetics, organics and hearing are parameters which, not withstanding the basic importance of binocular vision, must be written into any true equation which attempts to describe or measure visual space. To these we must also add parallax and perspective, illumination, aerial haze. color and color temperature, contrast, relative size of figure to ground, motion and an important matter of whether the observer is seeing phenomenally or rationally when he makes his space judgments.

These things should be enough to show why Hering's theory that retinal points carry hypothetical "depth values" is now generally rejected. An worthy as they unquestionably are, many of us cannot go along with the notion that the answers to our questions about visual space perception are to be found in physiology and geometric optics. The properties of the behavioral environment are different from man to man; quite different for the dog, the bird and the ant.

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PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshaw, Ph.D., at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PSYCHOLOGICAL OPTICS

March - 1958

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The invention and subsequent development of stereoscopic instruments made possible the measurement and study, by scientific methods, of binocular, tridimensional space and form perception.

It is difficult in the extreme to judge such matters, but, it would be doubly difficult to think of a more important development in the history and development of visual science. And, as one sits back to survey the field, again one is struck by the fact that so much, and yet so little, is really known about the processes and their determinants of how we see stereoscopically; that is, the true sizes, shapes, distances and perspectives of the real objects of our everyday experience.

For those who use instruments of this type there are a number of facts, developed by a number of investigators, which should be, but often are not, known. Could you make, mount and calibrate an orthostereoscopic set of test or training stereograms? I seriously doubt it. But, you say, "I don't have to make 'em, I just buy 'em and use 'em." True, but how? It is highly questionable whether you can *use* stereometric or training devices and know what you are doing unless you know a number of facts about them -- how they are made, calibrated and how they may be used and misused. It is hoped that in the most humble and most friendly spirit this paper may be of some help in making clear some facts which need to be clearly understood.

First, the making of stereograms photographically demands that you proceed quite differently than you would were you to set about making an ordinary view. Suppose the scene is a landscape containing a figure object. In the foreground at the sides are some shrubs and in the distance some trees, buildings, etc. Your figure object is, let us say, a visual test object, set up on a ring stand. The terrain between you and the horizon line is comparatively flat. First you must see that your test object is no nearer the vanishing point or most distant plane than about 1/20 of the total distance from the camera to the most distant objects in the scene, otherwise it will not stand out in relief as you want it. Second, you must stop down your lens to get sufficient depth of focus and depth of field so that *everything* in the scene from the nearest to the farthest object in the scene is maximally sharp. This is because we must duplicate *what the eyes see*. With 15mm. lenses in our eyes the scene is sharp from a few inches to infinity. So must the stereogram be.

Your camera must be dead level and you must take both a right and left eye picture. So you must decide what separation, or stereo base, of the lenses you must use. Now the 'normal' interocular distance is usually taken as 64mm., or 32mm. to the left and right of Czermak's line, the mid-line of the hypothetical cyclopean eye which does our stereoscopic 'seeing'. But here 'normal' is meaningless, because the correct base or interlens distance has to be computed. It may be anything from a few millimeters to as much as several million miles. One of the most famous stereos ever made, that of the planet Saturn and its rings was made with the camera here on the Earth, Saturn some 790 million miles away, with a stereo base of more than 1,000,000 miles. Such an interocular distance should not surprise you in these days of satellites and space travel. Another famous stereo of the same planet took three and a half years to make and showed the ring-system clearly detached from the planet which it 'normally' encircles.

So, you set up your camera to make an orthostereoscopic picture. You must first determine the width of the image you are going to use, whether projected on a screen or viewed in a scope. Then the distance from your lens to the film; then the width of the negative image; then the distance of the farthest and of the nearest objects in the scene. Then you can compute from a formula, or simpler, use a Polariod calculator circular slide rule to determine the correct interocular distance or stereo base for your R and L eye views. This will be correct in terms of geometric optics and photographic optics.

But hold on for a minute. We will come back to this later. Just now let us finish what we started out to do, that is, to make a pair of orthostereograms.

We develop the negatives. They are fine. We make a pair of prints. They are fine. We transpose and mount them-- but wait. Before they are usable we must mount them with suitable framing and window effects.

Starting with your two prints, the R and L eye views you have made, following all the rules thus far, now to prepare them for proper viewing you must first frame them properly. First you mask the tops and bottoms of the prints and the inside edges, keeping them in perfect vertical alignment. Then you measure the distance from the image of some near object to the inside edge in the left picture and transfer this distance to the right picture to establish its outside edge. Mask off everything beyond this outside edge of the right view. Now measure the full width of the right picture and transfer this to the left picture to determine its outside edge and mask off everything beyond this in the left picture.

You now have your R and L pictures framed for viewing. All parts can and will be seen stereoscopically. But now comes the matter of mounting, because this controls the very important factor of the 'window effect'.

The stereo view can be seen either in front of the plane of the card or mount or screem, or in back as if looking through a large window at the scene. Generally the latter is the preferred window effect, although sometimes it is desirable to put foreground objects slightly in front of the plane on which the projection occurs. It is obvious that such positioning effects are due to the relative positions of the R and L views with respect to the mid-line, that is to relative decentration. The formula used for determining the window effect is

$$M = \left(\frac{f \times b}{DW}\right) - B$$

where M represents the corresponding margins of the mask M, f the focal length of the objectives, B is the lens separation, and DW is the distance of the window from the station point of the observer.

Since if one uses stereo projection both in diagnosis and training it is quite important to know how to determine the ortho viewing position, that is where should the observer sit, with respect to the screen and the projector, in order that he may view the target scene orthostereoscopically. This is determined by the formula.

$$V = \frac{F/B}{PF}$$

where V is the correct viewing position, F is the focal length of the camera lens which made the pictures, B is the stereo base, and PF is the focal length of the projection lenses. For example, suppose that I wish to show a subject a stereo. The camera had a 3 inch lens; the pictures were made at the 'normal' base of 64mm; the projection lenses are 5 inch focal length. So, V equals 3/1 divided by 5 which is 0.6. If the projectors are set 10 feet from your screen you seat your subject 0.6 of this distance or 6.0 feet from the screen and he will be in the correct viewing position. Note that had I used 1/2 base in making the stereos, then the ortho position would be 3/0.5 divided by 5 and this would place the observer 1.2 times the distance or 2 feet back of the projectors from the screen. Any judgments of such things as apparent size and distance, or allelophoria or fusion ranges or limits must take careful stock of this factor, as Mr. Laymon's results in my laboratory have shown.

Two of the main factors in stereoscopic vision are those of parallax and perspective. If we increase the stereo base we deal with telestereoscopy and so increase perspective, because the R and L eyes now see farther around any solid object within reasonable viewing distance. If we diminish the base, say to one half, the opposite is true and we reduce perspective. If you have a protractor handy and wish to do a bit of home work take a sheet of paper and at the bottom lay off a base line and erect a perpendicular from a point that is half the length of the base line. Mark off stereo bases that are 32mm (16 on each side of the mid-line) which is one half base, another pair of points separated 64mm, that is 1 Base, another at 128mm, or 2 base, and another at 256mm or 4 base. You now have a nest of angles. Those angles should all be 64 degrees, but you can use larger or smaller ones if you prefer. Now the stereo space is contained only within the cone which is made by the overlap of the two angles resulting from each base. So the outsides are masked off. If you do this and measure the distance of the tip of the cone from the base line you will discover that this distance is directly proportional to the size of the base. In my rough drawing the cone tip is 100mm from the base line for the 128mm or two base; 50mm from the one base, and 25mm from the one half base.

Now suppose I am photographing a square white target at a fixed distance of 6 meters. I do this at 1/2, 1 and 2 times the 'normal' stereo base. It must be evident that when I change the base I change the ratio of the lateral size of the target to the limits of the angle of the cone. That is to say I am placing the target in a larger surrounding ground. What happens to my estimation or judgment of the apparent size of the target under these conditions? How does this compare to what happens when I decenter the targets by moving them closer together or farther apart?

We are able to speak with some assurance on questions like these because we have studied them experimentally in the laboratory and made sufficient measurements so that we can be sure.

Let us look for example at what happens to the apparent size of a 30 x 30 cm target at 6, 12, 24 and 48 meters photographed at 1/2, 1, 2 and 4 times the stereo base of 64mm.

The Effect of Changing Stereo Base
on Apparent Size, Decentration at Zero

	Target Distance (Meters)			
Lens Separation or Base	6	12	24	48
	(One Dimension of Match in mm.)			
32mm	144.14	67.42	34.02	20.46
64	129.98	62.14	31.96	19.00
128	123.75	59.71	30.29	19.58
256	125.62	58.38	29.54	18.58

These figures are one dimension in millimeters of the matches, being the arithmetic means secured by four well trained observers. The screen image was 126 x 126mm. Note that reducing the stereo base by 1/2 changes the perceived area from 130^2 or 16,900 sq. mm., to 144^2 or 20,736 or an increase in apparent size of 22.69%. But also more importantly note that the doubling or quadrupling the base makes no significant difference in the perceived size, and also that the 1/2 base effect has practically disappeared beyond distances of 12 meters.

Suppose now we decenter the images crossed (convergent) and uncrossed (divergent) at the various distances from 3 to 96 meters and measure the effects on the apparent sizes of the targets.

Four observers gave the following results:

Decentration	Crossed	Uncrossed
10mm	-6.9%	+4.6%
30mm	-9.6%	+16.0%
60mm	-12.9%	+29.5%

Crossing the images makes them appear nearer and smaller; uncrossing makes them appear farther away and larger, but to an altogether different amount. So we have to conclude that crossing and uncrossing are not functions belonging to a single continuum. They are two very different things.

These figures are means and, in my humble opinion, indicate one thing clearly and very importantly. For example, at 3 meters the uncrossed values for each of the four individual observers were: 2.4%, 18.3%, 5.2% and 36.6%. At 96 meters the same values were 23.5%, 14.8%, 70.4% and 37.8%. In other words the change in apparent size occasioned by decentration was a highly individual affair. Each of us lives in a space world the functions of which depend more on our structured organization of the sensory-cerebro-motor processes in perception than they do upon those of geometric optics.

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1928

PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshow, Ph.D., at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PSYCHOLCGICAL OPTICS

April - 1958

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In our previous papers we discussed the invention and development of the stereoscope; the making and proper mounting of orthostereograms; framing and window effects; the correct or ortho viewing position and closed with a comparison of the effects produced by changing the stereo base or inter-lens distance of the camera and of the decentration, crossed and uncrossed, of the stereo images.

There remains some matters relating to stereometry which the readers of these papers need to know. In the behavioral environment, space and form perception are as basic and fundamental a requirement as anything one can cite. The number of persons whose binocular tridimensional vision is more or less seriously limited is larger than most people think. Estimates run in the neighborhood of 20% of the population as being partially and seriously 'impaired' or stereo blind to a degree which limits them occupationally and behaviorally. The neighborhood theatres for example have almost abandoned the showing of conventional 3D movies; too many customers were unable to see and enjoy them.

In a large eastern city we measured the stereo size-distance judgment abilities of 1207 operators of gas and electric trolleys and buses. On each operator we had from the company each man's record of responsible accidents, that is those which cost the company money. When we took those who's apparent size and distance judgments were one standard deviation or more below the mean of the group, that is the micropsics, we found that they had proportionally 2 1/2 times as many responsible accidents as the 'normal' or the macropsics.

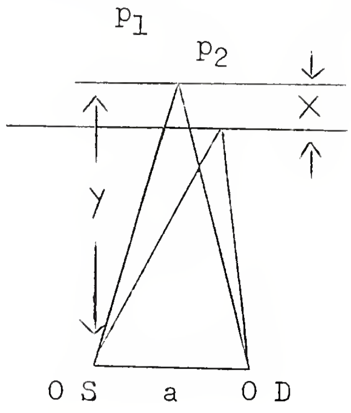
Any real examination and measurement of a person's functional or operational vision must include a proper assessment of tridimensional binocular stereoscopic vision. To do this one usually measures the parallax threshold, sometimes referred to as "stereo acuity," and the amplitude or range of stereopsis, that is the limits, crossed and uncrossed, within which the individual can achieve and maintain third degree fusion, that is to see the object or scene as single, three dimensional and properly positioned in space.

Sometimes this is done with devices and methods which are open to question. For example the Howard-Dolman apparatus requires the subject to look into a box in which two vertical rods, one stationary and the other movable, have to be placed so that both rods are perceived to be in the same plane at some fixed distance from the eyes. Other devices use rows of numbers or letters, one of which is decentered, and in successive rows the amount of decentration is reduced so that finally a limit is reached where the observer no longer can tell which of the seven numbers in the row stands foward or back of the plane of the rest of the numbers or letters in the row.

Still other tests or measuring devices use true stereo scenes on which various sorts of superimposed lines, dots, arrows and the like are printed in. Here the stereogram gives a true stereo ground for the 'probe body' or the figure or test object which has to be reported as to its position in the seen space.

In any case let us look, without discussing the merits and defects of any of the varieties of test devices, at the meaning and manner of determining the goodness or poorness of stereopsis, that is what is the parallax thereshold and how it is measured?

Let us represent a schematic situation by a simple figure:



Assume that p_1 and p_2 are two objects in the binocular field. P_2 is slightly nearer the observer than p_1. How near can p_2 be brought to p_1 before a limit is reached where the observer can no longer say that p_2 is nearer than p_1.

This is the parallax threshold of the measure of what is questionably called 'stereo acuity.'

The measure of the threshold is therefore the difference between the tangents. The tangent of the angle at p_1 is y/a, where a is the interocular distance.

Mathematically,

$$\tan(p_1 - p_2) = \frac{\tan p_1 - \tan p_2}{1 - \tan p_1 \times p_2}$$

So then,

$$\tan(p_1 - p_2) = \frac{\left(\frac{y}{a} - \frac{y-x}{a}\right)}{1 + \left(\frac{y}{a} \times \frac{y-x}{a}\right)}$$

Assume that y = 200 mm, the distance from the eyes to p_1, x = 10 mm, the distance from the eyes to p_2 and let a = 64 mm, the normal interocular distance, now we can write,

$$\tan(p_1 - p_2) = \frac{\left(\frac{200}{64} - \frac{190}{64}\right)}{1 + \left(\frac{200}{64} \times \frac{190}{64}\right)}$$

$$\frac{3.125 - 2.968}{1 + 9.2750} = \frac{0.157}{10.275} =$$

0.0152 radians (1)

The usual short formula, arrived at algebraically is that the parallax threshold P

$$P = \frac{ax}{y^2}$$

Substituting in the above assumption

$$\frac{ax}{y^2} = \frac{(64 \times 10)}{(200)^2} = \frac{640}{40{,}000} =$$

0.016 radians (2)

So the solutions in (1) and (2) differ by .0008 and can be disregarded.

Our answers in (1) and (2) are in radians. So, since we measure stereopsis in terms of angle seconds of arc, we must multiply the 0.016 by the constant 206,000 and this will give us the answer, in angle seconds, to the example, p^1 and p^2, described above. This comes to 3,296 angle seconds, which almost no one would fail to fuse.

The late Dr. Carl Shepard of Chicago worked out a set of standards using 19 seconds as the normal threshold value. His figures are as follows:

Percent Stereopsis	Angle Seconds
100	19
90	26
80	39
70	55
65	65
60	75
50	95
40	140
25	286
10	600
1	1300

The above figures were obtained with the "peg test" an Howard-Dolman type apparatus and so one may question how closely they would correspond to other more truly stereoscopic, i.e., picture type, tests.

Fischer states that normal stereo acuity is 2 angle seconds. Bourdon (1902) found it to be 5 seconds. Crowley (1905) got values from 2.3 to 20 seconds depending on contrast, illumination level and time of exposure; Howard (1920) got values of 1.8 to 10.6 seconds; Anderson and Weymouth (1923) got an average of 2 seconds as did Frübose and Jaensch (1923), and Langlands (1925) found values of 1.6 to 5 seconds.

Shepards 19 seconds is probably due to the fact that he used a different apparatus and procedure.

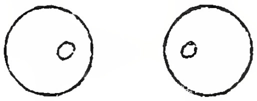
If the average is about 2 angle seconds then this corresponds almost exactly to the threshold for Vernier acuity. It is likewise interesting, from the standpoint of theory and interpretation, that excellent stereopsis can be obtained in after-images even if the figures have been presented to the eyes successively. Think what this means for theory!

In 1929 Langlands (Med. Res. Council Report No. 133, London) found that the parallax threshold was 9 seconds if the exposure was 3 to 100 milliseconds, 2 to 2.25 seconds if the exposures were from 3.16 to 10 seconds duration and still 2 seconds of arc under constant, that is prolonged, illumination. He also found that with practice the parallax threshold at 1/150,000 second duration could reach 10 seconds of arc. Some of you have witnessed my demonstration of the projection of a stereo view, made by Mr. Cris Lewis of Stereo Optical Co., from the air, of the Empire State Building. This can easily be seen in true stereo at an exposure of three millionths of a second, the illumination supplied by a General Electric quartz-mercury strobe lamp.

Measures of stereopsis by use of the Keystone 'airplane' series or the Stereo Optical vectographs or any similar device no doubt will give us a satisfactorily accurate measure of the least amount of crossed or uncrossed decentration or displacement fore or aft in space which can be perceived.

This is expressed in angle seconds or in prism diopters, and the percent stereopsis is based upon the assumption that if you can resolve anywhere from 2 to 19 angle seconds, that is perfect stereopsis. If the threshold is 1200 to 1600 angle seconds then you have about 1% stereopsis. Nowhere in the literature can one find the normative distribution of the percentile values which tell us for example the meaning of where one stands in a typical or general population who shows, say, a parallax threshold of 110 angle seconds. Shepards figures were taken from sampling a number of persons in various occupations which he rationally decided should have good stereo vision. Manifestly this is a very poor approach to the problem.

In our laboratory we have made many experiments over the years with a Kirschmann haploscope, sometimes called a 'universal stereoscope.' This carries the R and L stereograms on two circular target holders which can be placed in any desired orientation with respect to each other. Suppose you look at targets like this:



You see a megaphone with the small end near to you. Now if you rotate the right eye (or left) about its center you will be surprised at how large the range you can go with no change in stereo fusion. And if you turn the outside edge of the right stereo inward until the circle appears (outside the instrument) quite elliptical, in my own case 55° off the horizonal axis, still no perceptible change in third degree fusion is seen. But now if you restore the images to the 'normal' position and incline either one forward or back from the top, fusion breaks for me at as little as 6° displacement, and I am reasonably sure that I have normal or better stereo vision.

The Kirschmann has another interesting capability. The target holders can be adjusted with one image nearer or farther from the entrance pupils than the others. Image areas on the retinas can be computed in terms of Gullstrand's reduced eye by the formula

$$i = 17.05 \frac{O}{D}$$

where O is one dimension of the object in millimeters; D is the distance in millimeters and i is the principal dimension of the image at the retina, and 17.05 mm is the distance from the node of the lens to the retina.

We can thus produce something like an aniseikonia by delivering a small image to one eye and a larger one to the other eye and we can make the relative image sizes anything we choose. If you make the observations you will find that good fusion is maintained over a surprising range of image size differences. Puzzling isn't it, that a critical image size difference of about 2% *in aniseikonia*, makes such a functional difference in the vision of some but none at all in other people.

All of the foregoing is presented to show that this cardinally important function of seeing three dimensional space and form is still in its research infancy. Much needs to be done and must be done We can't do the kind of measuring job needed for specifying proper training procedures or corrective procedures until we work out a better theoretical understanding, better instruments and methods

There are those, unfortunately, who take a limited view of the problems of stereo vision, claiming as does one writer (AMA Arch. Ophthalmol., 1958, *59*, 4-17) for example, that the whole problem is *physiological*, implying that experimental and theoretical psychology has no part to play in the scientific attack upon the problems.

To me, *physiological* means geometry, physics and biochemistry--a world "with man left out," to quote Titchener. None of us would question for a moment the value of studying the analytic, *molecular* processes in space and form perception. We simply insist that we must also look to the molar processes, which are the moleculars *in extension*. When such "physiological" description can tell me how I can hear a melody, consonance and dissonance, fugue, or why one face is beautiful and another ugly, or how I see *my* world, then but not before, will I be willing to abandon scientific psychology and join them.

VOLUME 30 — OPTOMETRIC EXTENSION PROGRAM PAPERS — (POSTGRADUATE)

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OPTOMETRIC EXTENSION PROGRAM 1928

PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshow, Ph.D., at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PSYCHOLOGICAL OPTICS

May - 1958

Series 18 No. 8

Before we conclude the consideration of the problems, theories, apparatus and methodology in studying and measuring binocular, tri-dimensional visual functions, one further fact should be stated. This has to do with the proper and sometimes improper use of anaglyphs.

When I look out the window down upon my back yard garden I note my friend Mr. Cardinal sitting on top of a steel post paying a visit to some food placed there for him. If I alternately close and open my two eyes the post changes its position with relation to other objects in the visual field moving, at this distance, perhaps a foot or two. If I notice the vertical wood bar separating the window panes, which is about 30 inches from my eyes, and now alternate my two eyes, the wood bar now moves to the left or right of the steel post by a meter or more depending on which eye I use to align the bar and post.

If I just look naturally and binocularly both the bar and post seem to remain in the same relative spatial orientation. We know of course that seeing tridimensionally is done because my two eyes looking continuously are alternating at a rate not far from one per second thus producing a transform of a species of the phi or apparent movement effect which I have learned to see as the common phenomenon of depth and distance.

I can photograph the scene and with polarizers, properly oriented before my eyes, see the same depth and distance effects. Or I can place a red filter over the left view and a green filter over the right one, and wear a pair of complementary filters reversed and see the same depth effect, or at least what appears to be the same effect. This is anaglyphic stereopsis.

If now we set up 45° black lines on the complementary red and green backgrounds and use these targets to measure alternation rate, for example, we are at once in trouble. First, the black and red or green lines, will alternate as figure and as ground and you can never be sure what your count means. Second, you find that you can voluntarily control the rate of alternation of the anaglyphs but not of black diagonal lines on a white ground. In perception, color and form behave entirely differently, that is reciprocally one to the other. If we wish to study contrast effects, for example, brightness contrast will be maximal when color contrast is minimal and visa versa. So, if you feel you must use anaglyphs, better watch out and be sure what you are doing. You may be reporting artifacts rather than normal operations of binocular tridimensional vision.

But now for the business at hand. In previous papers we have attempted to show that interest in stereoscopic seeing goes back centuries. In spite of this fact our description and understanding of three dimensional visual phenomena is still far from complete. For example you and I know that there is little or no agreement among those professionally interested in vision as to how to measure malpositioning in binocular space. If I used the word phoria I can only be sure that it will mean many things to many people; that there will be much argument and little agreement. Some will say that "you can't change a phoria."

Even in spite of the fact that anomalous space projections are being corrected by proper training with fine success, many unfortunate people are being told that an important binocular space perceptual function which is one of the most highly susceptible to practice effects is fixed and immutable. If one is bold enough to ask modestly, "How do you know? What is your evidence?" Then look out.

Almost everything about vision, strange as it may seem, is controversial. From the very earliest days of optics and catoptrics the problem of the present paper has been with us. It runs like this: The crabapple tree out there reflects light to my eye which contains a convex lens. In an eye model the tree will form an image which is upside down. It is widely assumed that the same image formation occurs in my eye as in the box camera model. (Shades of Gullstrand!) How then do I see the tree as it is, that is, right side up?

Kepler, the astronomer raised the problem in 1604. Scheiner in 1625 and Descartes in 1637 removed the sclera from the back of a bull's eye and on thin paper saw an image of the object of focus. And in 1692 W. Molyneaux championed the constancy hypothesis, that perceptual extension corresponds to retinal image extension exactly. He assumed that the size of the retinal image was immediately apparent to the observer, which it is not, and as von Kleindt showed much later that even if one grants the existence of 'retinal images' there is little or no correlation between 'image' area and phenomenal size and distance.

We owe to Molyneaux however the first clear notion of the relativity principle. He said "erect and inverted are only terms of relation to up and down....but the eye or visive faculty takes no notice of its own parts, but uses them as an instrument only." Recall that at about the same time Berkeley had shown that an object could be considered inverted only when the world of touch is brought into relation to the world of sight, and that Mach later extended this notion that perception of the apple tree involves also the semi circular canals, kinaesthetics, and that visual perception as vision alone was no acceptable solution to the problems of form, space, position, size and distance. As much as anything it was Mach's insistence on the role of motor functions, manipulating, handling, stepping off, throwing, walking, etc., that paved the way for modern theory.

In the mid 1890's Professor George M. Stratton, an experimental psychologist at the University of California, made an epochal experiment, publishing a paper "Some Preliminary Experiments on Vision Without Inversion of the Retinal Image" (Psychol. Rev., 1896, 3, 611-617). Professor Stratton has gone to his reward but the influence of this important seven pages marches on.

To see things upright, Stratton said, you have a choice of two theories: (1) projection; objects are projected back into space in the directions in which light rays fall upon the retina. The crossing of the rays demands the inversion of the image. (2) Eye movement theory; eye movements and the direction of such movements are the means by which we judge spatial relations of objects in the visual field. Upper and lower require up and down movements of the eyes to bring the objects into clear vision. But an upward movement brings into clear vision only what lies below the fovea, so here too the upright perception of an object requires retinal image inversion.

Stratton stated the problem simply like this: **Is the inverted image a necessary condition of our seeing things in an upright position?**

He placed two plus lenses of equal refractive power in a tube at a distance equal to the sum of their focal lengths. Thus the eye sees everything inverted, otherwise the image remain unchanged. All other light was excluded, otherwise "the purity of the experiment would be lost." To make the apparatus lighter two double convex lenses were used. The visual field subtended an angle of 45°.

Because of convergence difficulties he used monocular vision, with the unused eye open with its tube occluded with black paper.

Stratton was his own subject. The first day he wore the tubes from 3 p.m. to 10 p.m. and his eyes were bandaged during the night. The second day he wore the tubes from 9:30 a.m. to 10 p.m. The third day from 10 a.m. to noon, then removed them.

He wore the tubes a total of 21 1/2 hours, a time "too short for undoing a life long habit of interpreting visual signals" but gave "interesting indications of what would result if such experience were considerably extended." All his observations were made indoors, watching the street scene below. He noted the movements of his own feet and hands in grasping and handling objects, head and shoulder movements.

Describing the course of his experiences he said "all images were at first inverted. The room seemed upside down. Hands extended in the visual field from below seemed to come from above. Images were clear but seemed unreal, misplaced, false. Memory images brought over from normal vision still continued to be the standard and criterion of reality."

"Present perceptions were for some time translated involuntarily into the language of normal vision--signs to determine how and where and object would appear if it could be seen with restored normal vision. Things were seen in one way and thought of in a far different way."

"Body movements were awkward and uncertain and full of surprises. Only when made regardless of vision - as in complete darkness - were movements performed with reasonable security and directness."

In walking Stratton reported his "limbs began actually to feel in the place where the new visual perception reported them to be. The vivid connection of tactile and visual perceptions began to take away the overpowering force of the localizing lasting over from normal vision. The seen images thus became real things just as in normal sight."

Peripheral objects finally came "into harmonious relation with the present perception," though the central field was "entirely isolated and out of harmony with the larger whole." "The new field widened and moved out so as to include them." "By the third day (wearing the inverting lenses) things had thus been interconnected into a whole by piecing together the parts of the ever changing visual field."

"The feeling that the field was upside down remained throughout the experiment." But when "full attention" was given to outer objects "these frequently seemed to be in normal position." Any abnormality "seemed to lie in myself." At other times the inversion "seemed confined to the face and eyes alone."

"On removing the glasses on the third day there was no peculiar experience. Normal vision came instantaneously without any disturbance in the natural appearance or position of objects."

Stratton concluded that neither of the two theories - projection and eye movements - are acceptable since they failed to explain "how the scenes could even temporarily have appeared upright when the retinal image was not inverted." "The difficulty of seeing things upright by upright images seems to consist solely in the resistence offered by the long established previous experience."

"The relations of touch and movement corresponding to visual field relations would give us upright vision regardless of any retinal image position." And finally Stratton concluded that "a person whose vision had from the very beginning been under the conditions of the experiment artifically produced, could never possibly feel that such visual perceptions were inverted."

Next we will summarize several experiments which grew out of Stratton's original research and look at the meaning of the evidence for theory.

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PSYCHOLOGICAL OPTICS

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PSYCHOLOGICAL OPTICS

June - 1958

Series 18 No. 9

It was Goethe, poet, dramatist, philosopher and scientist, who once remarked that one of our most common faults is to transform "a problem into a postulate," and then relax as if the problem is solved.

From the earliest observations with the camera obscura and the long series of the developments of apparatus and experiments which followed upon it, it was logical to presume that the image of the camera obscura or of the pinhole camera was the paradigm or model of the same thing within the eye -- the "image on the retina."

So, small wonder that George Stratton decided to put to test the problem as to why, assuming for the argument that there is a retinal image exactly copying the object "out there," we see things right side up, or as they are to touch, when the image is upside down and reversed right and left?

When Stratton made his observations some 64 years ago, he knew some but not all of the reasons why we simply have to reject the 'classical' concept of the retinal image. Stratton pointed out that we do not see things on the retina. The retina is a mechanism for transforming light energy density distributions in patterns of afferent volleys of comparatively slow and weak virtual transfers of ions in nerve conduction. In the optic bundle there can be no resemblance as to form, size or position between the distribution of the energies there and the light pattern at the retina. Boring once pointed out that a green pea, dropped one centimeter on a glass plate would produce enough energy to stimulate every eye of every man who ever lived!

Hecht showed that if 100 units of light arrive at the cornea to enter the eye opening and if you deduct the amount reflected from the cornea, front and back surfaces of the lens, absorbed and scattered in the media, reflected back from the retina itself (skiascope or retinoscope), about 8% of the light actually is able to serve as a stimulus to the receptors.

But only 30% of the photosensitive elements fire at the onset of stimulation for something like 5 to 10 milliseconds then they are off. Fifty per cent fire at the cessation of the stimulus leaving only 20% of rods and cones to fire throughout the entire period that the stimulus excites the eye.

Now the afferent impulses don't all go to the 'visual cortex,' by a long way, that is to Brodemanns areas 17, 18 and 19. At about the striate region those nerve currents are modulated and added alegbraically (they are sine waves) to those incoming from the ears, the skin, the muscles, tendons and joints. Adrian showed that the nervous processes from any sense organ are the same regardless of their sensory origin and that they differ only in wave length, wave amplitude and frequency.

Van t' Heuven in 1925 showed that in the visual cortex energies from the periphery of the eye are condensed into a small wedge shaped region in areas 17 and 18 and those from the fovea are spread out extensively in all directions around this. Nothing remotely resembling any 'image' in form, size, position, brightness, etc., could therefore possibly be seen in the brain. As neurophysiologists have shown there is in the brain a diffused spread of nervous energy, some sort of coded signal which the organism can become aware of and can report its attributes, meaning, classification, etc. But without the effectors and their feedbacks there is no seeing. Never has the evidence been so overwhelming that no one ever sees 'a retinal image' simply because there are no 'retinal images' to be seen. Denial of the retinal image does not deny that we do see things in perhaps the most intricate and amazing set of functions found anywhere in nature. It says simply that this is an instance of solving a difficult, and as yet unsolved, problem by giving it a name, just as Moliere did in his famous satire on the medical profession, "Le Medicin Malgre Lui."

Stratton said we cannot say that either the retina or the visual cortex can be said to be the organ of vision. His answer to the problem of vision with retinal inversion was that we have to learn to interpret the visual signal in terms of active touch and movement. That is, we learn to see things not on the retina or in the brain, but out there in space where we have to do something about them or where they do something to or for us. This is what we mean by external reference.

Stratton's 1896 experiment drew fire immediately. Hyslop in England, for example objected to Stratton's position that upright vision is due to "the harmonious interorganization of motor, tactual and visual experience." Hyslop's contention was that Stratton's experiments were too limited (one eye only, himself as observer only, too sweeping generalization, etc.) was published in the Psychol. Review, 1897. Then Stratton wrote an extended reply in the British journal, Nature, which Professor Stratton once told me was by far the best expression of his work on the problem; and I thoroughly agree.

But since Stratton wrote in 1896, 1897 and 1898, there have been a number of repetitions and extensions of his work on the problem. In general, every one of the repetitious, variations and extensions of Stratton's pioneer experiments reached the same conclusion: We see things in space not in the same orientation as the distribution of energy on the retinas or in the brain but in terms of the behavior space of the perceiver. This is a complex set of structured and organized relations of the perceiver coacting with his environs, part of which are inside and part beyond the boundaries of his physical body.

In 1928, P. H. Ewert repeated and extended Stratton's experiment. His subjects, 3 in number, wore binocular inverting lens tubes for 14 days (175 to 195 hours). He investigated touch, sound and visual localization. The visual field was 34.5 degrees wide. In general his results were in agreement with those of Stratton. At first there was disorientation occasioned by the inverting lenses. The subjects rapidly learned touch localization and there was no evidence that a tactual area shifted to the position indicated by the 180 degree inversion visually. On removal of the lenses there was an immediate return to the normal visual, tactual, motor coordinations.

In 1928, P. T. Young made an experiment in which he wore a pseudophone, a device for delivering sounds from the right side to the left ear, and vica versa. He wore the pseudophone for 18 days, one hour each day for the first 9 days, two hours daily for the next 6 days, and the last three days it was worn during the entire waking period.

At first auditory localizations were reversed but were normal if the source of the sound was seen or its position known. Visual-auditory localization was learned to a point similar to localization before wearing the pseudophone. The results, like Stratton's, showed a trend and should have been extended over much longer time to be conclusive.

Foley, in 1938, placed lenses similar to those of Ewert on a rhesus monkey for 7 days. Progressive improvement was found over the 7 days. When the lenses were removed there was a short period of confusion followed by a return to the normal status.

In 1952 Snyder and Pronko made a more extensive experiment. Their tubes were binocular, with only a 20° field with very small entrance pupils at the "slightly converged" ends of the tubes. One observer (Snyder) wore the inverting lenses for 407 hours during 30 days. Learning of card sorting, Minnesota rate of manipulation test, Purdue pegboard, and mirror tracing was done before, during and after the wearing of the inverting lenses. In mirror tracing time per run dropped from 56 seconds to 13 seconds in 21 runs. When the lenses were put on the time was 66 seconds on run 24, 38.4 seconds on run 25 and this dropped to 8.0 seconds on run 51. The lenses were removed and on run 52 the time was 18.8 seconds. On 53 it was 12.0 seconds. One run 62, the time was 8.4 seconds. On the last run No. 73 it was 8.6 seconds.

The lenses caused disruption of performance at first, but the learning curve became at once the same shape and slope as that in normal learning and continued on at the same general level after the lenses were removed. This was typical of all the 'tests' of the experiment.

The authors point out in discussing their results that not only inversion but also restriction of the peripheral field was an important factor. They conclude that "perception of up and down, right and left, is entirely relative to the conditions obtaining during the time in which the person is building up perceptual responses," and that the "high degree of uniformity of visual as well as other perceptions of people is merely a reflection of the universality of standard conditions that surround their development."

In short all the studies of all the investigators point up the same conclusion: We see things in the positions, distances, shapes, etc., which we develop in the organized and unified behavior field of the active touch, locomotion, manipulation, hearing, etc., of the organism in its kinetic and ecological life. All sensory inputs only have meaning in so far as they relate to the broad syncretic activities of the organism in its environs. Along with Professor E. R. Guthrie, mental life is muscular life. Stop movement, implicit as well as overt, and there remains only oblivion.

So, to the deceased Professor George M. Stratton, and to his followers, we owe a great debt. He broadened the horizon of vision.

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PSYCHOLOGICAL OPTICS

From the laboratory of experimental psychology of Samuel Renshaw, Ph.D., at Ohio State University, optometrists receive some of the most valuable procedures for applied optometry.

PSYCHOLOGICAL OPTICS

July - 1958

Series 18 No. 10

It is time now to review briefly the trend of the nine papers preceding this one of this series. We started with a brief exposition of the views of George Berkely. Berkely was a confirmed idealist. For him the only "real" things existing were those mental processes called sensations. He shrewdly observed that concepts of position, form, size, distance, etc., could not be achieved through vision alone. Attributes of objects seen were modified by and dependent upon the input modulating and transforming effects from the other sense modatities--that is, form the active touch and movement, from hearing, the semicircular canals, etc.

Berkely's position thus was an out and out elementarism or atomism. Various signals came to us following stimulation. If aware of them they were called sensations. In some way these were combined by the organism to make the perceptual unities. The parts were summed to make the whole.

Then we looked at the views of Ernst Mach, who presented a position diametrically opposed to that of Berkely. Mach's position was that of a monistic physical phenomenalism. "Sensations" for him were physical events, highly complex electrochemical events, but all experiences were nothing more than the single order of physical energy effects and these were integrated into our experiences in some manner, poorly understood particularly in the 1880's and 1890's by the sensory-cerebo-motor system. Mach was never clear or explicit on this point.

Two things impress one in reviewing the history of visual science as exemplified by these two great contributors. First they were both atomists or elementarists. Things were summations of small 'elements' or parts combined in some speculative and unproven way to make the whole. The fact, for example, that a melody was something more than a mere succession of separate tones was recognized but the problem of how each tone contained some small fraction of the melody, but could not be discerned by any form of analysis when sounded alone, remained unsolved.

Theirs was the position analogous to the cell theorist in biology (from about 1865) who heed that all tissues, organs and organic functions, were mere assemblies of millions of single cells, not one of which alone contained any hint, like the single tones in the melody, of the fact that an organ, say the brain or kidney, produced effects which could not be predicted from anything known or discovered or discoverable about the structure or properties of any single cell.

These difficulties and the criticisms of all forms of atomism or elementarism were recognized as early as the cell theory itself. For example, at the same time Du Bary, a German botanist, put it this way: He said, "Plants build cells, not cells plants." This was a statement of the organismal theory in biology. It had its analogs in physics with the development of field theory. In a complex circuit for example, what happens in any one part depends on the relative conductances, resistences, impedances, etc., in all parts of the circuit. Each part is in no sense, except the wrong one, an independent entity.

In so far as they may be taken as representative it now seems quite clear that a second objection to both the above atmosite theories is that they sought the ultimate "explanation" of seeing in physiology and neurology. There is no question that the problem of how the eyes, brain and muscles work in the carrying on of our daily activities is a problem for the biological sciences. Some day perhaps we shall know. At present we can only guess, with our guesses loaded by some exact information, but by no means enough to account, in any satisfactory way, for the sequence of events which, for example, led Newton and La Place to invent the calculus or Bach and Brahms to create or compose their immortal music.

Then we looked at another milestone or turning point in the history of visual science. This was represented by the work of George Stratton and others. As soon as the notion of external reference became clear; as soon as Baldwin (Mental Development in the Child and in the Race) and others showed that binocular, stereoscopic space and form develop under the guidance and control of the active touch and movement, then it became clear that the roles of perception, learning and memory had to be written into any decent or defensable concept of vision as one of the most fundamental functions of an organism (particularly vertebrates) in its environment.

Both Mach and Berkely noted that those born blind and with sight restored surgically had to learn to see. Dozens of studies (e.g., Pratt, Nelson and Sun) long before the Gesell group, on mental development outogenetically, clearly demonstrated that children through proper reinforcing experiences learn to make proper discriminal judgments of form, size, position, distance, motion and of brightness and color.

All of which led to the necessary and inescapable revision of S → R (stimulus-response) doctrine. Tolman and others introduced the notion of the intervening variable - that is, that between stimulation and response the organism programs, structures, organizes and perceives what must be done in the way of response to lead to the consummatory act. So S → R became S → O → R.

But inquiries soon demanded a revision and extension of this thinking. Kinetic and ecological and ethological studies showed that what the organism was doing before "the stimulus" was presented, designated by A factors, had to be added so that A → S → O → R became the notation; and more recently another set of factors, the F or feedback had to be added following the R, since these were the maintaining and directing agents transforming the A, the S, and the O factors in subsequent learning to get along in the organism's environs.

In biology came the studies of C.M. Child and his students (1941) and of Paul Weiss, on patterns and problems of behavior and on the concept of gradients and the embryogeny of behavior forms, to mention only two prominent scholars in this field.

In psychology we had the neglected arguments of Mary Whiton Calkins and of William McDougall for a self psychology, both valiant attempts to show that behavior is a transitive process done by some person who has dignity, rights, duties, not only in a bio-social sense but certainly psychologically. Strange indeed how many "educated" people refuse to accept the principle that "the proper study of mankind is man!" Chemistry, physics, biology, mathematics, yes, bow from the hips in reverence, but psychology, man's attempt to study his own operations for better understanding and control, no!

Part of this unfortunate business can be lain at the feet of those, past and present, who look to physiology for the needed answers. Some of us are convinced that they cannot and will never be found there.

About the same time Mach was influencing thinking and research (about 1890) von Ehrenfels, a German philosopher became interested in the problem of form-quality. Why Mach came so near and yet missed the mark, of seeing that totals had to be something different from the sums of their parts we can only leave to speculation. Dilthey in 1894 saw that the "whole is more than the sum of its parts." And he was joined by Meinong, Husserl, Witasek, Schumann, Stern, Avenarius and others, in a rigorous examination of his generalization.

I mention these things only to show that there has been a growing distrust of those theories which are based on some form of counectionism (association, conditioning, etc.) of hypothetical 'elements' (reflexes, sensations, etc.) to produce the perceptual unities. It seems like a realization that "a house divided--cannot stand."

Much of present day teaching and research in vision is elementaristic. Much of it is organismic. Does it make any real difference from what point of view one operates? Most assuredly it does. Suppose, for example, you wish to measure as accurately as possible foveal acuity. You construct an apparatus so that in looking into a tube with one eye you see a bright patch subtending, say, 2 1/2°. You use König bars so that you can determine the minimum separable and constant separable thresholds, using appropriate psychophysical methods. Thus, by reduction, you eliminate all variables but one. In so doing you are being very rigorously scientific. But are you?

It all depends. Under the constraints you have selected, yes. But if one asks what does this tell me about foveal acuity as I look out the window, or under any condition in which spatial summation from the periphery can and does change the foveal picture, as Granit and his students have shown, or as McFadden demonstrated in his dissertation, then the answer is no. Both kinds of investigations are valuable. It all depends on the question as to what is your problem, and in terms of what theoretical framework are you willing or able to draw your conclusion.

In the first decade of the present century a series of experiments on seen movement and the problem of the interpretation of the results came to have a great effect upon subsequent thinking and experimentation or many problems in vision.

We shall continue on with them next time.

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PSYCHOLOGICAL OPTICS

August - 1958

Series 18 No. 11

Scientific progress occurs very often by a re-examination of the fundamental scientific concepts, i.e., through search and research. Fundamental concepts in science are those of space, time and motion. In Vol. 12, No. 7 (1952) of this series I began by saying that "motion generates space and form. It is inseparably bound up with the concept of space-time."

Interest in the phomena of seen movement is very old. We are told that it goes back some 5,000 years B. C. In ancient Egypt a prince, to honor his father, caused to be erected a circular temple about which were 176 pillars upon the surface of each of which he had painted a figure of his father with his arm raised in the successive postures of a military salute. A charioteer, driving rapidly around the temple would thus see the king saluting kinematoscopically, that is as we might see him in the movies. We can speculate as to the mystical and probably political consequences on those not too well able, as often we all are, to discriminate 'real' from apparent movement.

Motion pictures arose out of two events: The argument between Leland Stanford, Sr., and a friend as to the order in which the race horse's feet hit the ground when he paces, trots or runs. So they set up a battery of cameras (20 or 30) the shutter of each was tripped when the horse's chest pulled the silk threads equally spaced. 'Fanning the prints' let the viewer see in slow motion the actual sequence of legs and hoofs, and the arguments were settled. Then George Eastman said why not put the emulsion on a long strip of gelatine like material, and Hollywood was soon in business.

In visual psychology we have long been concerned with the many problems arising out of the perception of real and apparent movement. For one thing it has long been known that motion can be seen where both the object out there and the observer are absolutely stationary. This is static motion, paradoxical as this expression may sound.

If you are a block away and the two red lights at a grade crossing are alternately on and off for about a second each, you see a single light moving back and forth between the two positions. This called for attempts to account for the 'in-between' processes. When an obstruction like a board was set up midway between the two lights and they were made to alternate, one observer would report that the moving single light now takes a bow shaped path over the top of the obstruction; a second observer says nothing of the kind, the light bows down around the bottom; and a third observer says, "Boys, you are both wrong - it moves in back (i.e., in the third dimension) around the board." Small wonders the interest in the problem because all three were honestly reporting three kinds of perceptions all originating from the same patterns of retinal stimulation.

Max Wertheimer was born at Prague in 1880, and took his doctorate Summa Cum laude under Oswald Külpe at the University of Würzburg in 1904. In the summer of 1910 he went to Frankfurt where he set himself to re-examining the concepts of see movement by making extensive experiments.

The two principal observers in these experiments were Wolfgang Köhler, able physicist and mathematician as well as psychologist, and Kurt Koffka, also a keen and well trained scientist.

With the activating leadership of Wertheimer, these three set about to find some real answer to the problems of seen movement.

If you recall that this was the time when the top doctrines, thinking and theorizing were those of Müller, Helmholtz, Hering, Wundt, Külpe, etc., and that the prevailing mode of solving any such problem as apparent motion was "von unten," "from below," that is to say it was an elementaristic or atomistic attempt to put together by some process of summation the sensations, reflexes, single nerve currents, etc. to synthesize the total experience.

Dissatisfied with the unsuccessful attempts to follow this line Wertheimer named the apparent motion of the two lights seen as a single moving light the phi-phemonenon. And the problem certainly moved farther and farther away from atomistic explanations when trained observers such as the top flight scholars, Köhler and Koffka, and several others all reported what Wertheimer designated as 'pure phi' that is the experience and observation of motion without noticing what it is that moves! Calling it phi was the clear realization that the phenomenon was something to be explained. The appeal to elements led only to an unsatisfactory and unaccepted "explanation."

In 1912 Wertheimer published a paper "Experimentelle Studien über das Sehen von Bewegung," (Experimental Studies on the seeing of motion) in the 60th volume of Zeitschrift für Psychologie.

No one can question the high importance of this paper. It became important not because the results of the experiments were new or different or revealing, but because Wertheimer in it proposed a new explanation of the phenomenon.

This was in terms radically different from any stimulus - response elementarism. Rather it generally could be aligned with the organismal theory in biology, and with the field theory of physics, chemistry, astronomy. Here the scientists for once agreed with the philosophers such as von Ehrenfels, Husserl, Meinong - and experimental psychology, particularly that segment interested in visual perception, moved forward with the expanded and expanding concepts derived largely by Wertheimer, Köhler and Koffka.

If any reader doubts this I sentence him at once to a long and careful reading of Köhler's very important contribution, printed only in German, "Die Physische Gestalten."

It is well to bear in mind that most of the great and influential discoveries, movements, theories in science represent the works not of a single person, but usually a 'team' of workers or a succession of investigators, theorists or interpreters often over periods of many years - even centuries. Such is the case with the problem of seen motion, and so stating I do not wish to be understood to take away one iota of the great accomplishment of Max Wertheimer and his co-workers Köhler and Koffka, because I feel certain that the world of science will continue to pay them the homage they most richly deserve.

Wertheimer could find no constant relation between 'the stimulus' and phenomenal or seen movement. It could not be a 'bundle' of sensations. Ordinary analysis of the experience of motion could not and did not yield any set of sensory or nervous constituents. Movement was a total experience of a human observer which conventional methods of analysis only destroyed. All the gears, wheels, cams, pinions of my watch can be dissembled and laid out on the table. But they can't and will not keep time thus picked to pieces. Analyzing experiences which are unitary wholes, said Wertheimer, leads only to artifacts, to the destruction of any possibility of understanding phenomena.

Wertheimer did not deny the existence of the stimuli which anteceded the experience of seen motion. Rather he insisted that both stimulation and the 'in between' processes and the experienced or perceived phenomenon all had to be considered as belonging to a single, inseperable, total system.

It is hoped that no one who reads this

paper will form the conclusion that the experiments and the new theoretical look (in 1912!) stopped at the boundaries of the province of visual apparent motion. The general theorem of an organismic, or wholistic or Gestalt approach was far more general and was extended in the 45 years since its inception to all types of problems in experimental psychology, particularly to perception, learning, memory, thinking and problem solution, and even to abnormal psychology and psychiatry.

But, before we can present in any fair way, a summary of the Wertheimer theory and its effect subsequently, we shall need to do two things: Show how the subsequent studies on seen movements since 1912 by many others have verified and extended Wertheimer's original position, and to show how the studies of the 1912 paper led to the formulation of a theoretical framework for a psychological field theory which grows year by year as research advances, and finally how this kind of approach to all visual problems, aided by new and important developments in mathematics, points to the future with high hope that we may leave the world to our children with concepts richer than that which likens man to a nickel-in-the-slot machine, an ultimate probabalistic robot.

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PSYCHOLOGICAL OPTICS

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Last time we pointed out that when he made a careful and critical re-examination of the experiments on visual apparent movement, Max Wertheimer could not satisfactorily reconcile the things he saw and demonstrated in his laboratory with the prevailing theory. Recall that in 1912 Germany was the world leader in experimental and theoretical psychology. The dominant point of view was the structural psychology of Wundt, Külpe, Brentano, and leaders of this type. They held that the methods of psychological investigation should follow in the footsteps of the parent science, physics. The problem was to analyze or reduce all complex phenomena to their simplest constituent elements. These 'elements,' that is things incapable of further division or analysis, were (1) sensations; the simplest and most primitive awareness of red, for example, not red rose or red book, for this was then a percept and had meaning; (2) simple images, the persisting after-effects of sensory experiences in time after the exciting stimuli were no longer acting on the sense organs; and (3) simple feelings, mere pleasantness and unpleasantness.

Leading scholars strove by introspective analysis to reduce any and all complex experiences to patterns of these three 'elements.' In this 'atmosphere,' Wertheimer's work on seen motion brought him at once in direct contact with the problem of form-quality of von Ehrenfels, Husserl, Meinong and others. Too often analysis destroyed far more than it clarified.

Motion could be seen (pure phi effect) where nothing was seen to move except motion itself; disparate images falling on corresponding retinal points or Panum areas simultaneously still would only produce depth if figure alternation were going at a rate within the optimal range; two tones were heard as a whole series of harmonics not present in the air. Watching a car back out into the street and turn presented a four dimensional space-time-motion perceptual problem which could not be handled satisfactorily by the then current type of atomistic analysis.

It took brave souls to take a position opposed to that of the great leaders of the time. It took courage and more, real ability to defend the dissenting position. Such was Max Wertheimer. He saw clearly that, as Köhler once said, "every perceptual theory must be a field theory." He looked at a circle of gray on a background that was half red and half green. When a thin black strip was laid on the mid intersection of the red and green and bisected the gray circle, the half circle on the red at once took on a greenish cast and that on the green looked pink. There simply had to be something more in such perceptual experience than could be discovered in no matter how detailed a description of the stimuli. When the gray circle was seen as a unit no contrast induction from the surround took place. When it was made into two segments, its 'behavior' in relation to its surrounds became something quite different.

Considerations of this sort led Wertheimer naturally to a critical re-examination of the real relations of the physical events of the body and the perceptual events correlative to them.

This was the perennial dualism. It still stalks among us. Our bodies are physical, biochemical mechanisms, "of the earth earthy." This no one can question, (but some ecclesiates do!) Our perceptual and conceptual experiences are said to belong to a different order of events, called mental processes. Can the latter events be described and explained in terms of the former? Should we seek the answers to space, time, form, motion, all perception, in the facts of nurophysiology? If we had an exact map of the energy distribution in the brain when we see a three dimensional picture or hear a symphony orchestra sound the chords of an impressive movement, could we tell, from looking at the map, what we are seeing and hearing? The answer is no.

There is general agreement among those who know most about the structure and functions of the brain and nervous system that in spite of the imposing mass of neurophysiological knowledge of the system (e.g., Adrian, The Physical Basis of Perception) we cannot "explain" how we perceive, or how we remember (R.W. Gerard, The Mechanism of Memory), by anything now known about the structure and functions of the sense organs and the brain. Some scholars believe that the time will come when it can be done;others dissent and hold that the answers can never be had to psychological problems in biochemistry and nurology.

Wertheimer gave much brilliant critical thought to this problem of the relations of structure and function. He came to the conclusion that the answers to how we see as total living whole organisms in our own habitats can not be found in no matter how detailed an exposition or description of the molecular processes of the nerve cells or nerve nets.

There must be, he said, some kind of constancy of relation between the molecular processes of the body structures and the molar processes of perceiving, understanding, learning, remembering, thinking, etc. Wertheimer proposed a solution to this problem.

He said in essence, why not think of both the molecular and molar events as phases or episodes in a single organic continuum? Why not regard the molar processes merely as the molecular processes in extension? This was the doctrine of isomorphism.

It said simply that the two things are really nothing more than different stages or phases of single organismic operations; that the hunt for the physical, invariant patterns of activity underlying form, size, position, distance, etc., was a futile and fruitless one, and that we should better devote our energies to a direct frontal attack on the problems of how we see things than to seek the answers in other divisions of science whose entire fortunes are cast with the principles of atomism, that is seeking the facts and interrelations of molar processes in the endless regress of analysis into the physically smaller and smaller and smaller sub-units of the system, each step of which took one only farther and farther away from, rather than nearer to, the proper understanding of molar experiences.

Of course such position or view point was, in 1912 as in certain quarters in 1958, unpopular with all those trained and committed to atomistic ways of thinking and experimenting.

Wertheimer found it doubly difficult to state his position clearly because semantically he had to use words which by long established usage had grown to have only for most readers only atomistic meanings. But Max Wertheimer was a brave and devoted soul. He believed literally that if you know the truth, the truth will make you free. He had courage and was thrice armed with what to him was certainly a just cause.

Suppose for the moment we put aside prejudice and agree with the principle of isomorphism in biology and psychology. What happens then to the 'classical' psychophysics, that is, to the intensity relations between physical stimulus properties of intensity, duration, area, etc., and the consequent phenomenal or perceptual experiences of brightness, loudness, sweetness, and the like? Since most of us have been trained in the concepts and habits of thinking of atomistic science, let me recommend to you this 'exercise': work out a comprehensive and clear 'explanation' of just noticeable differences in terms of the isomorphic field theory. Then dust off your mathematics and take the classical 'laws' of Weber $(\frac{\Delta I}{I} = K)$ and of Fechner $(S = K \log R)$, where S represents sensation intensity and R represents stimulus intensity and show how they would have to be re-written or scrapped and new ones developed to fit the facts, let us say of the problem of how many discriminable size differences can the eye make in spots of light increasing in size from 3 mm to 300 mm in diameter, assuming that you know how to keep brightness constant as size changes!

From 1923 to his death 20 years later Wertheimer and his students made many important contributions to the literature.

From these experiments he formulated the rules or 'laws' for the formation of figures in fields or grounds and for the better understanding of how to control the perception of forms. These I have summarized in Vol. 6, 1946, Nos. 6-12, of this series and it would be a good notion for you to re-read them at this time.

If I know the size of a screen image and the distance of the observer from the screen, I at once recognize that the mathematical function which describes best this relation is the law of tangents. I say to myself "this is one of those" figuratively. This process of identification is very fundamental. Ternus, one of Wertheimer's students, was able to show, for example, that "phenomenal identity is preserved by the whole as such and not just by relations between the parts." 'Parts' thus are man made artifacts and are not basic realities. They are what they are because of the "where, when and with whom" and not because of their possession of intrinsic physical properties.

It would require many papers such as this to summarize the brilliant and important work of Max Wertheimer and his students. Obviously it cannot be done here.

Shortly before his death in 1943 Wertheimer completed the manuscript of his little book on Productive Thinking, (Harpers, N. Y., 1945.) If you have not carefully read it by all means do so.

Of primary importance to us are such concepts as grouping, centering, organization, etc. If you do anything in visual training you are absolutely obliged to know this literature thoroughly. Not many do. The importance of these processes in vision is that they carry on out into the most ultimate reaches of thinking, problem solving, reasoning and creativity. Read and ponder the Productive Thinking; Katona's Organizing and Memorizing; and Karl Dunckers A Qualitative Study of Productive Thinking. Then you will be well on the way to a fuller understanding of Binet's famous assertion that "the beginning of reasoning lies in perception."

This volume was undertaken to present for you some of the great contributors and their contributions to the advancement of visual science. In 'my book,' Max Wertheimer was one of these. He will go down in history as a great pioneer. He gave us the 'anlagen' of a defensible point of view as to the mind-body problem; he contributed to a broader and better way of dealing with the problems of perception; and he carried these on over into the highest processes of productive thinking, showing how anyone can be trained to do it better. Here lies the hope of the future of our culture and civilization. When will education catch on and catch up?